A Study of the Effect of Trawling in the Newfoundland and Labrador Northern Shrimp (*Pandalus borealis*) Fishery on Mortality and Damage to Snow Crab (*Chionoecetes opilio*)

E.G. Dawe, K.D. Gilkinson, S.J. Walsh, W. Hickey,
D.R. Mullowney, D.C. Orr and R.N. Forward

Science Branch
Department of Fisheries and Oceans
P.O. Box 5667
St. John's NL Canada A1C 5X1

2007

Canadian Technical Report of
Fisheries and Aquatic Sciences No. 2752

Fisheries and Oceans Pêches et Océans

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques*.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de Rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Canadian Technical Report of
Fisheries and Aquatic Sciences 2752

2007

A STUDY OF THE EFFECT OF TRAWLING IN THE NEWFOUNDLAND AND LABRADOR NORTHERN SHRIMP (*PANDALUS BOREALIS*) FISHERY ON MORTALITY AND DAMAGE TO SNOW CRAB (*CHIONOECETES OPILIO*)

by

E.G. Dawe, K.D. Gilkinson, S.J. Walsh, W. Hickey, D.R. Mullowney,
D.C. Orr and R.N. Forward

Fisheries and Oceans Canada
Science Branch
P.O. Box 5667
St. John's NL A1C 5X1

© Her Majesty the Queen in Right of Canada, 2007.
Cat. No. Fs 97-6/2752E ISSN 0706-6457

Correct citation for this publication:

Dawe, E.G., Gilkinson, K.D., Walsh, S.J., Hickey, W., Mullowney, D.R., Orr, D.C., and Forward, R.N. 2007. A study of the effect of trawling in the Newfoundland and Labrador northern shrimp (*Pandalus borealis*) fishery on mortality and damage to snow crab (*Chionoecetes opilio*). Can. Tech. Rep. Fish. Aquat. Sci. 2752: 43 p.

TABLE OF CONTENTS

ABSTRACT IV
RÉSUMÉ V
INTRODUCTION 1
METHODS 2
DIRECT ESTIMATION OF MORTALITY AND DAMAGE 2
POTENTIAL FOR DAMAGE AND INFERENCES FROM VARIOUS DATA SOURCES 5
RESULTS 7
DIRECT ESTIMATION OF MORTALITY AND DAMAGE 7
POTENTIAL FOR DAMAGE AND INFERENCES FROM VARIOUS DATA SOURCES 12
DISSCUSSION 14
MORTALITIES 14
CARAPACE DAMAGE 15
LEG LOSS OR DAMAGE 15
FISHERIES INTERACTIONS 17
CONCLUSIONS AND RECOMMENDATIONS 18
ACKNOWLEDGMENTS 18
REFERENCES 19

ABSTRACT

Dawe, E.G., Gilkinson,K.D., Walsh S.J., Hickey, B., Mullowney, W.D., Orr, D.C., and Forward, R.N. 2007. A study of the effect of trawling in the Newfoundland and Labrador northern shrimp (*Pandalus borealis*) fishery on mortality and damage to snow crab (*Chionecetes opilio*). Can. Tech. Rep. Fish. Aquat. Sci. 2752: 43 p.

The impact of commercial shrimp trawling on the Newfoundland and Labrador snow crab resource was assessed from a variety of experiments as well as fishery and survey data. Direct assessment of snow crab damage and mortality caused by encounters with shrimp trawl rockhopper footgear was investigated through trapping, trawling, and video experiments. A ROV (remotely operated vehicle) equipped with a video camera was used to survey experimental trawling corridors in St. Mary's Bay to compare damage to crabs before and after intense trawling. Experiments were also conducted off the northeast Newfoundland coast using a secondary trawl attached under the body of the main trawl to collect crabs, for assessment of damage that had encountered but not captured by the main trawl. None of these experiments found direct evidence of mortality or carapace damage to crabs due to encounters with shrimp trawl footgear. However, the results strongly suggested that intense trawling, at levels considerably higher than those imposed by the commercial shrimp fishery, could cause increased leg loss in the order of 10%. Broad spatial comparisons indicate that areas exploited by the shrimp fishery were not associated with relatively high incidence of leg loss, and that other factors such as predation or handling practices in the snow crab fishery may have a greater effect on leg loss than encounters with trawls. Other fishery and survey data support our conclusion that the shrimp fishery does not impose a substantial mortality on snow crab.

RÉSUMÉ

Dawe, E.G., Gilkinson,K.D., Walsh S.J., Hickey, B., Mullowney, W.D., Orr, D.C., and Forward, R.N. 2007. A study of the effect of trawling in the Newfoundland and Labrador northern shrimp (*Pandalus borealis*) fishery on mortality and damage to snow crab (*Chionecetes opilio*). Can. Tech. Rep. Fish. Aquat. Sci. 2752: 43 p.

Nous avons estimé l'impact de la pêche commerciale de la crevette au chalut sur la ressource en crabe des neiges à Terre-Neuve-et-Labrador en regard des résultats d'une série d'expériences et de données de pêche et de relevés. Nous avons également mené des expériences de capture du crabe des neiges au casier et au chalut et de saisie d'images vidéo dans le but de faire une évaluation directe du niveau de mortalité et des dommages causés à ce crustacé par le faux-bourrelet sauterelle des chaluts à crevettes. En outre, nous avons utilisé un engin télécommandé muni d'une caméra vidéo pour faire un relevé de corridors de chalutage expérimental dans la baie St. Mary's aux fins de comparaison des dommages aux crabes avant et après le chalutage intense. Nous avons aussi mené des expériences au nord-est de Terre-Neuve à l'aide d'un chalut secondaire fixé sous le corps du chalut principal pour récolter, aux fins d'évaluation des dommages qu'ils avaient subis, des crabes qui se trouvaient sur la trajectoire du chalut principal mais qui n'y avaient pas été capturés. Aucune preuve directe de mortalité ou de dommages à la carapace des crabes causés par le faux-bourrelet sauterelle du chalut à crevettes n'a été relevée lors de ces expériences. Les résultats laissent toutefois clairement entendre que le chalutage intense, à des niveaux nettement plus élevés que ceux imposés par la pêche commerciale de la crevette, pourrait causer une perte accrue de pattes, de l'ordre de 10 %. Des comparaisons à une vaste échelle spatiale indiquent qu'il n'y a pas de relation entre les zones de pêche de la crevette et une incidence relativement élevée de perte de pattes. D'autres facteurs, tels la prédation ou les méthodes de manutention des prises de crabe, peuvent avoir un effet plus marqué sur la perte de pattes que les chaluts. D'autres données de pêche et de relevés étayent notre conclusion à l'effet que la pêche de la crevette n'est pas à l'origine d'une mortalité substantielle chez le crabe des neiges.

INTRODUCTION

The snow crab (*Chionoecetes opilio*) and northern shrimp (*Pandalus borealis*) fisheries represent the two largest and commercially important fisheries in Newfoundland and Labrador. Crab and shrimp fishing grounds overlap considerably from the southern Labrador shelf to the northern Grand Bank (NAFO Div. 2J3KL, Fig. 1). The snow crab fishery is prosecuted in "fleets" or long-lines of conical pots baited with squid or fish whereas the northern shrimp fishery utilizes shrimp otter trawls. Concerns have arisen from commercial snow crab harvesters as to the destructive effects commercial shrimp trawling imposes upon snow crab populations.

The snow crab fishery began in 1968 and was limited to Division 3KL (Fig. 1) until the mid 1980s. The resource was very large throughout the 1990s and the fishery grew to over 3500 license/permit holders by 1999 (Dawe et al. 2003). The resource surrounds the entire island portion of the province and extends north off Southern Labrador. It is most intensely prosecuted in Div. 3KL on deep (100-500 m) muddy substrates. Although there has been a decline in exploitable biomass in some areas in recent years, the snow crab fishery had a total allowable catch (TAC) of 49,943 t in 2005 (Dawe et al. 2006).

Northern shrimp has been commercially fished off Newfoundland and Labrador since the late 1970s. The resource extends along the entire Labrador continental shelf south to the northern Grand Bank (NAFO Div. 2GHJ3KL, Fig. 1) with the fishery most intensely prosecuted in the area north of the Grand Bank, i.e. NAFO Div. 2GHJ3K. Recent landings have been at all time highs, totaling 99,000 t in 2004 within NAFO Div. 2J3K, where this fishery overlaps with that for snow crab. Shrimp abundance and biomass indices remain high (DFO 2005).

The effects of bottom trawling on the brood stock have been suggested as a determining factor for the collapse of the red king crab (*Paralithodes camtschaticus*) population in Bristol Bay, Alaska, following the onset of intense groundfish trawling activity in the late 1970s (Dew and McConnaughey 2005). The intensity of bottom trawling along the Newfoundland and Labrador shelf had declined substantially from the 1980s to the early 1990s with the collapse of the groundfish fisheries (Kulka and Pitcher 2001). The levels of trawling intensity along the outer continental shelf have subsequently increased with the growth of the shrimp fishery. Studies on effects of trawling activity on red king crabs suggest low injury rates of ≤10% resulting from encounters with bottom trawling footgear of various types (Donaldson 1990; Rose 1999). There is no information on indirect mortality due to effects of trawling such as damage to the carapace, loss of limbs or degradation of habitat (Armstrong et al. 1993).

In this paper, we investigate the effects of shrimp trawling on damage and mortality to snow crabs. We present results of a multifaceted study designed to investigate direct effects of shrimp trawling on snow crabs. We also consider our experimental results in relation to the degree of interaction between the snow crab and shrimp fisheries on the eastern Newfoundland-southern Labrador shelf, based on a variety of data sources.

METHODS

DIRECT ESTIMATION OF MORTALITY AND DAMAGE

Trawling corridor experiments

St. Mary's Bay (Fig. 1) was selected as the site for experiments to quantify the physical impact of trawling on crab because of high abundance of crab in relatively shallow waters, within the depth limits for operation of the remotely operated vehicle (ROV) that was used for video observations. The research vessel CCGS SHAMOOK served as the surface platform for all experiments except crab trapping.

Two experimental trawling corridors, each 500 m x 200 m, were established on muddy substrates (Fig. 2) and subsequently named the Outer- and Mid-Bay corridors. An inner bay corridor had been planned but was not accessible because of commercial gear in the area. Depths at the Outer- and Mid-Bay corridors were about 130 and 100 m, respectively. The experiments were designed to use video surveys to estimate the physical condition of crabs in the corridors before trawling was introduced and then later after the trawling was completed.

Trap sampling: Trapping experiments were conducted in the vicinity of the trawling corridors from the chartered vessel *Coot's Pond Osprey,* with the intent of sampling both prior and subsequent to the experiments within the trawling corridors. On each sampling occasion four fleets of Japanese style conical crab pots were set in strings of six, each consisting of four large-meshed (135 mm mesh) and two small-meshed (25 mm mesh) traps. Pre-trawling fleets of gear were set outside the perimeter of the first (Outer-Bay) experimental corridor to determine density of crab in the area and to collect baseline data on catch rate and damage. Post-trawling trap sets were located both outside and within each trawling corridor. Trapping was conducted only after trawling at the second (Mid-Bay) site because this area was not originally intended to be the second study area, but was selected after the original inner-bay site proved to be inaccessible. Crabs from the two small-meshed and two large-meshed traps were sampled from each fleet (i.e. end traps were not sampled).

Video surveys: Trawling and video experiments were conducted during June 1-11, 2005. Video surveys of trawling corridors were conducted using a highly maneuverable Phantom class ROV that was deployed in free-swimming mode from the surface vessel. The ROV could be maneuvered very close to individual crabs in order to assess condition (see below). Video transects were positioned across the trawling corridors, perpendicular to the path of trawling to ensure maximum likelihood of encountering trawl tracks and areas of disturbance in post-trawling surveys (Fig. 3 and 4). Sub-surface navigation was achieved using a Tracklink USBL System consisting of an over-the-side mounted USBL transducer pole with a transponder attached to the ROV umbilical cable directly above the ROV and linked to the ship DGPS. In each corridor, a one-day pre-trawling video survey was conducted along these transects. A video survey was conducted along transects on the day immediately after trawling (12 hrs. post-trawling) in each trawling corridor. Post-trawling video surveys in the second (Mid-Bay) corridor were also conducted on the third and fifth day following trawling.

A Remotely Operated Towed Vehicle (ROTV) was initially used during trawling, at about 80-110 m depths, to record observations of crabs encountering trawl footgear. Unfortunately, only about an hour of video was obtained before the ROTV malfunctioned and could not be used for the remainder of field experiments. Crabs caught during these initial tows in relatively shallow water were enumerated and sampled. Some observations of crabs encountering footgear were also acquired using headline-mounted video cameras.

Experimental trawling: The otter trawl used was a 2 bridle Yankee 36 shrimp trawl with a 9 m wingspread, rockhopper footgear with 30 cm diameter discs and 70 cm length toggle chains (Fig. 5). Trawl sets were standardized tows that swept through the trawling corridors lengthwise, approximately perpendicular to video transects (Fig. 3 and 4). An attempt was made to trawl over the entire area of seabed in each corridor once. Trawling in each corridor took approximately 10-12 hrs. Contact with the bottom started and ended beyond the boundaries of the trawling corridor to ensure that the entire length of each corridor was trawled. Trawl mensuration was monitored by SCANMAR. Fourteen trawl sets were conducted in the Outer-Bay corridor and sixteen in the Mid-Bay corridor. Entire trawl catches, including crab samples were discarded well outside the trawl corridors.

Biological sampling and treatment of data

Trap and trawl samples: Snow crabs were collected from each trap or trawl set and sampled for sex, carapace width (CW, mm), and shell condition, as well as chela height (CH, 0.1 mm) for males and maturity for females. Shell condition was assigned one of three categories: (1) new-shelled – recently molted crab with high water content which would not be retained in the fishery;

(2) intermediate-shelled – crab that had molted in the spring of the previous year with generally clean shells and would be retained in the fishery; (3) old-shelled – crabs that had not molted in the past two years, exhibiting more worn and fouled shells. Damage to the carapace and damage or loss of limbs was also assessed on each crab. Carapace damage and leg loss or damage were categorized as either new (fresh and clean in appearance) or old (exhibited signs of healing). Catch rates were calculated, as number/trap haul for traps and number/tow for trawl, by sex and shell condition.

Video data: Crabs observed in video surveys were counted and missing limbs were tallied. Missing limbs could not be assigned as new vs. old because of lack of clarity. From the video, crabs were assigned to one of three size groups based on observed carapace width (CW) modes from the trawl catches: 1 (<36 mm), 2 (36-71 mm), and 3 (≥71 mm). Crab densities (number/minute) as well as carapace damage and leg loss were calculated for totals and for each size group.

Significance of differences in numbers of missing limbs before vs. after trawling was assessed using a one-sided Fishers Exact Test.

Trawling experiments with secondary trawls

A commercial shrimp vessel was used for trawling experiments with a secondary trawl attached underneath the main trawl on shrimp fishing grounds in areas of Div. 2J and 3K (Fig. 1) for a period of ten fishing days each. In Div. 2J, the *Shandy Pauline II* was used from June 25 to July 07, 2005 and in Div. 3K the *Krista Paul* was used from July 08 – July 18, 2005. The trawl used was an IMP 920 commercial shrimp trawl with a 15.3 m wingspread and rockhopper footgear with 30 cm diameter discs. A secondary trawl, with independent footgear was attached underneath the main trawl to collect crabs that encountered the main trawl footgear and passed underneath the gear (Fig. 6). The fishing line of the main trawl served as the headline for the secondary trawl. The secondary trawl consisted of three retainer bags attached to a common footgear that was independent of the main trawl footgear. The footgear of the secondary trawl was a rubber-encased cable of 7 cm diameter. The main trawl sorting grate was disabled for all experiments.

Trawling experiments were conducted with the main trawl footgear rigged in one of two modes in attempts to identify damage from two types of interaction with the trawl:

1) Commercial fishing mode; the fishing line was toggled about 70 cm above the footgear. Very few crabs were expected to be caught in the main trawl. Crabs sampled from the secondary trawl would have passed either over or beneath the main trawl footgear.

2) Research sampling mode; the fishing line was attached directly to the rockhopper footgear with very short toggle chains in the manner that DFO's survey trawl, Campelen 1800 shrimp trawl, is rigged. Samples obtained from the main trawl were crabs that passed over the footgear.

It was recognized that new carapace damage and new leg damage or loss in trawled samples (whether from the main or secondary trawl) are likely to have incurred after capture, within either of the trawls. Therefore, initial sampling in normal commercial fishing mode (as described above) was considered to be the reference mode for assessing damage and leg loss levels from subsequent experimental manipulations. With the trawl rigged in the commercial mode two additional variations of the footgear were added. The first experiment involved applying additional weight (chain) to the main trawl footgear to enhance bottom contact, toward determining if a heavier footgear digging into the substrate would induce higher damage or leg loss. A second subsequent experiment involved removing the secondary trawl to conduct 5 consecutive tows along a common tow path and then installing the secondary trawl to collect samples during the 6^{th} repeat tow. Samples from the 6^{th} tow were compared to the commercial reference mode to determine effects of repeat towing on damage and leg loss levels. Sampling of crab in all experiments involved assessing carapace damage, leg loss, and catch rates as described previously. Significance of differences in carapace damage and leg loss between the reference mode and each of the experimental configurations (i.e. weighted footgear and repeated trawling) were determined using Fisher's Exact Test.

The experiment based on research sampling mode was designed to determine whether carapace damage and leg loss were more common in crabs from the main trawl (those crabs that passed over the footgear) than from the secondary trawl (those crabs that passed under the footgear). This comparison was not possible however as very few crabs were caught in the main trawl. However all crabs were sampled and damage and leg loss levels from the secondary trawl were compared with those from the commercial reference mode.

POTENTIAL FOR DAMAGE AND INFERENCES FROM VARIOUS DATA SOURCES

Analysis of fishery data

Fishery logbook and observer data from 1995 to 2005 for both snow crab and shrimp were analyzed to determine the extent of spatial overlap between shrimp and snow crab fishing effort. The purpose of this analysis was to infer impacts that shrimp trawling in Div. 2J3KL might exert on the snow crab population.

Snow crab fishing distributions from logbook data were spatially compared to shrimp fishing distributions from observer data (large-vessel fleet, 100% observer coverage) and logbook data (small-vessel fleet) on an annual basis for the period 1995-2005. An analysis of the extent of seabed area trawled by shrimp vessels was also carried out. From observer data on small and large vessel shrimp fleets, footrope widths (m) were multiplied by tow speeds (km/hr) and duration (hr) to calculate total area trawled (km^2) for each shrimp trawl tow. Areas trawled for each set were assigned to 5' x 5' cells on the fishing grounds based upon trawl set starting positions. From this, an understanding of trawling intensity by area in the shrimp fishery was developed for association with the results of repeat trawling experiments in Div. 3K. Trawl tracks were assumed to be spread throughout each 5' X 5' cell. Cumulative area trawled within each cell was estimated by year, divided by individual cell area and then multiplied by 100 to obtain percentage of total area trawled within each cell by year. Calculation of areas trawled in individual cells was limited to only Canadian vessels because observer and logbook records for international fishing trips were not fully available. Therefore the extent of interaction, between the two fisheries, and percent of total area trawled in Div. 2J3KL is likely underestimated, particularly in areas outside of the 200 m limit (Fig. 1).

From the large shrimp vessel observer data, trends in snow crab by-catch (kg) and CPUE (kg/set) by year and division were analyzed. Large vessel shrimp observer data were complete for the entire timeframe, 1995-2005, for all three divisions. From logbook and observer data in each division, annual number of snow crab sets from the snow crab fishery were compared to the annual number of shrimp sets from the shrimp fishery, and the total areas trawled by the shrimp fishery. To more fully understand spatial relationships between the two fisheries within each division, the area fished was compared between fisheries. The annual numbers of 5' x 5' cells fished in the snow crab fishery were compared to the annual numbers of cells fished by the shrimp fishery and plotted against the numbers of cells common to both fisheries. For these overlapping cells, yearly percentage of the area trawled (or re-trawled) within each cell was calculated to assess the extent of trawling on commercial snow crab fishing grounds.

Trends in snow crab commercial CPUE in an area of the Hawke Channel closed to bottom trawling since 2003 (Div. 2J, Fig. 7) were compared with CPUE trends outside the closed area to further infer effects of shrimp trawling on snow crab mortality.

Other data sources

Two additional datasets were available that included incidence of leg loss. One dataset was from at-sea sampling by observers throughout the Div. 2J3KL fishery in 2000 and 2001. Observers sampled representative trap catches in their entirety. Crabs were sampled for sex, size, and shell condition, as described

above for the 2005 studies. Observers also noted total number of legs missing (old plus new). The second dataset was from the 1995-2005 fall multi-species bottom trawl survey series in Div. 2J3KL. Details of survey design, gear, and sampling protocols are described in Dawe et al. (2006). Sampling in 2000 included enumeration of missing legs.

RESULTS

DIRECT ESTIMATION OF MORTALITY AND DAMAGE

Trawling corridor experiments

Prior to the commencement of trawling and video surveys, trap sampling in the areas adjacent to the Outer-Bay trawling corridor in St. Mary's Bay, yielded high catches of snow crabs. Large (about 70-130 mm CW) old-shelled males represented the bulk of the catches (Fig. 8, Table 1). A secondary group of small (about 40-60 mm CW) new-shelled (recently-molted) crabs of both sexes was present in low numbers. Samples acquired within the Outer-Bay corridor during trawling differed considerably from adjacent trapped samples with an intermediate-sized (38-68 mm CW) group of recently-molted (both soft and new-hard shelled) crabs of both sexes dominating (Fig. 9). This group corresponded to the smaller group weakly represented in the trapped samples. A secondary group of smaller new-shelled crabs (8-23 mm CW) of both sexes was present only in the trawl catches while the group of large old-shelled males that predominated the trap catches was poorly represented in the trawl catches. Trap sampling after the trawling experiment resulted in catch rates and size distributions that were similar to those from trap sampling before the trawling experiment (Fig. 10).

The trawled samples likely reflect the demographic structure of the local population generally (i.e. modal size groups present) but progressively smaller crabs are likely under-represented, as catchability of crabs by trawls increases with crab size. (Dawe et al. 2002). The striking difference between the trapped and trawled samples is primarily due to low catchability of small crabs in the traps due to competition with abundant large old-shelled males.

In total, eight ROV video transects (four pre-trawl and four post-trawl) were completed across the Outer-Bay corridor (Fig. 3). Transects depicted reflect the path of the surface vessel, as it was not possible to track the ROV at the beginning of the experiment due to technical problems. The quality of video recorded during both pre-trawl and post-trawl ROV surveys was excellent (Fig. 11-12). In total, fourteen trawl sets were completed in the Outer-Bay corridor. The percentage of the total area inside this corridor that was swept by the footgear (wing to wing) was 45% (Fig. 3). Bottom contact by the footgear

appeared consistent as evident from the numerous furrows present in the post-trawl video (Fig. 12).

No pre-trawl trapping was done adjacent to the Mid-Bay experimental corridor. The size distributions of crabs captured during trawling in the Mid-Bay corridor were similar to those from the Outer-Bay site except that the smallest crabs were rare in the Mid-Bay corridor (Fig. 13). Post-trawling trapped samples from the Mid-Bay site displayed catch rates and size compositions that were similar to those from the Outer-Bay corridor (Fig. 14); however the minor group of intermediate-sized crabs (especially females) was absent from the Mid-Bay site where the trap catches were almost exclusively comprised of large, old-shelled males.

Ten pre-trawl ROV transects were completed across the Mid-Bay corridor (Fig. 4) with excellent visibility and video quality (Fig. 15). The circuitous path of the ROV is evident, as navigational equipment was now fully functional and it was possible to track the ROV. The ROV tracks represent a combination of surface vessel drift and maneuvering of the ROV. In total, sixteen trawl sets were completed on the day following the pre-trawl ROV survey, with total footgear swept area covering 58% of the corridor (Fig. 4). Post-trawl video observations were acquired on three different occasions following trawling. On the first day after trawling, water conditions were turbid and visibility poor due to suspended sediment from trawling the previous day (Fig. 16). Four ROV transects were completed before winds increased, necessitating aborting ROV operations. On the third day after trawling three post-trawl ROV transects were completed, and two additional transects were completed 5 days after trawling

Changes in snow crab densities from video after trawling were not consistent between the two experimental corridors (Fig. 17). In the Outer-Bay corridor, density increased after trawling. In total, 72 crabs were observed in 46 minutes (1.56 crabs per minute) before trawling whereas 239 crabs were observed in 67 min. (3.57 crabs per minute) after trawling. In the Mid-Bay corridor, density decreased from 345 snow crab in 213 min. (1.62 crabs per minute) before trawling to 294 crabs in 273 min. (1.08 crabs per minute) after trawling, with all post-trawling data pooled. This decrease was partly due to poor visibility on the first post-trawling occasion when only 42 crabs were seen in 97 min. (0.43 crabs per minute, Fig. 17). With the omission of these data, a total of 252 snow crabs were observed in 176 min. (1.43 crabs per minute) over the subsequent two attempts.

No direct mortality was observed in ROV video taken in either trawling corridor. Also, no carapace damage was observed in ROV videos (Fig. 18). Old carapace damage was uncommon, at less than 1% for traps as well as trawl. New carapace damage was absent from trap samples but was evident in 2.3% and 2.1% of trawled crabs from the Outer-Bay and Mid-Bay sites respectively. Similarly, new leg loss or damage was virtually absent (0.2-1.0%) from trapped

samples but was more prevalent in trawled samples, at 19% and 6% for the outer-bay and mid-bay corridors respectively (Fig. 18). This higher level of new leg loss in the trawl samples relative to the trap samples likely reflects post-capture damage to relatively small and delicate (new-shelled) crabs within the trawl. Old leg loss was higher from traps (46-58%) than from the trawl (21% and 25%), due to the relatively old age of trapped samples. These percentages of total leg loss from traps closely reflect the findings of a previous study in which at-sea sampling by observers showed that the incidence of crabs with lost limbs in the Div. 3L fishery in 2000-01 ranged between 45% and 55% (Fig. 19).

Total leg loss from ROV video observations ranged 0.25-35%, lower than from either traps or trawl (Fig. 18). This may be due to different demographic sampling biases among traps, trawl and ROV, or it may reflect incomplete detection of lost limbs in ROV video. It was not possible to distinguish new versus old leg loss from video. Total leg loss from video was higher after trawling than before trawling in both corridors. The incidence of pre-trawling and post-trawling leg loss were lower in the Outer-Bay corridor (13% and 24% respectively) than in the Mid-Bay corridor (22% and 31% respectively), with the poor quality video observations from the first day after trawling in the mid-bay corridor removed.

The data on old leg loss from trawled samples and total leg loss from video indicate that leg loss is usually manifested in a single leg lost (Fig. 20). About 10-25 % of crabs had lost a single leg, about 5% had lost two legs, while loss of four or more limbs was quite rare. These trends in leg loss are consistent, albeit in lower percentages (particularly at the 1-2 leg loss level) with those from the 2000 Div. 3L fall multi-species trawl survey, for most sizes of crab (Fig. 21). The effects of poor visibility in the Mid-Bay corridor during the first day after trawling are evident in that less than 10% of crabs were observed by ROV to have one leg lost (Fig. 20). The incidence of crabs with lost legs from the pre-trawling ROV survey in the Mid-Bay corridor agreed well with the incidence of old-leg loss from the trawled samples, as would be expected. However, this was not the case in the Outer-Bay corridor, where the percentage of old leg loss from the trawl was higher than that from pre-trawling video observations and more closely reflected that from post-trawling video observations. In both corridors, increases in the proportions of leg loss between pre-trawl and post-trawl ROV observations were statistically significant ($p<0.05$, Table 2), with the poor quality video observations from the first day after trawling in the Mid-Bay corridor removed. Those post-trawling increases in leg loss were similar between the Outer-Bay corridor (12%) and the Mid-Bay corridor (9%).

Observations of crab encounters with trawl footgear using the ROTV were of limited use. Snow crabs passed quickly through the field of view of the camera due to the tow speed required for normal trawl performance. Only about an hour of video of trawl footgear was acquired before the ROTV malfunctioned. Analysis of the ROTV video and some video from a headline-mounted color camera did

reveal that the travel wire (used to keep the rockhopper discs from rolling) in the bosum area was positioned toward the front (as opposed to the top) of the footgear (Fig. 22). This was caused by the use of long toggle chains to attach the fishing line to the footgear, which resulted in the travel wire moving counterclockwise to the front. Increasing the length of belly lines of the trawl would likely have compensated for the longer toggle chains. However, with the travel wire of the bosum being located at the lower front rather than at the top it created an area where some crabs entangled themselves between the wire and the rockhooper discs and remained throughout the trawl tow. Limited video observations from the headline-mounted camera suggested that 40% of crabs passed beneath the footgear, 30% passed over the footgear, and 30% became stuck to the footgear (Fig. 22). The effect of this footgear configuration on damage to crabs is unknown, but should have resulted in increased damage to those crabs that became stuck to the footgear. It likely had no effect on degree of contact with the substrate as was apparent from the videos taken by the ROTV and headline mounted cameras.

Trawling experiments with secondary trawls

Catch rates and composition: Limited success was achieved in experiments using secondary trawls in Div. 2J. The vessel's doors and trawl warps were too heavy for the experimental trawl resulting in poor bottom contact. Thirty sets were executed, with 910 crabs caught and sampled from the secondary trawl (Table 3). Accordingly, new carapace damage and new leg loss incurred by crabs as a result of these experiments could not be considered typical.

Trawling experiments in Div. 3K were more successful than those in Div. 2J. In Div. 3K, the experimental trawl was similar to the vessel's commercial trawl, footgear contact with bottom was considered typical of commercial shrimp trawling and 8584 crabs were sampled from 24 sets (Table 3).

Trawling in Div. 3K in commercial fishing mode (6 sets) captured snow crab of all sizes with a primary mode of small (21 mm CW) new-shelled crabs of both sexes (Fig. 23) and a second mode of larger (47-68 mm CW) old-shelled mature females. Trawling with extra weight on the footgear (8 sets) captured a sample population very similar to commercial mode but yielded a higher CPUE for most size groups (Fig. 24), likely attributable to heavier bottom contact. There were more pre-recruit males (71-95 mm CW) in these samples than in samples taken from commercial fishing mode. The size composition of crabs acquired after repeated trawling along a single tow path (6^{th} set) was dominated by small (8-38 mm CW) new-shelled crabs of both sexes (Fig. 25). The catch rate for this size group, as well as the prevalence of soft-shelled crabs (shell condition 1) within it were higher from the repeat trawling experiment that from any of the other experiments. Trawling in research fishing mode (4 sets) captured almost

exclusively snow crab between 8-68 mm CW of both sexes with very few larger crab present in the catches (Fig. 26).

Damaged carapace and leg loss analysis: Prevalence of old carapace damage was compared among trawled samples of male crabs from Div. 2J and 3K trawling experiments, St. Mary's Bay trawling corridors, and St. Mary's Bay initial sets conducted during ROTV observations (Fig. 27). Old carapace damage was uncommon (<5% of crabs) for most size groups. In St. Mary's Bay and Div. 2J, old carapace damage was almost exclusive to crab <60 mm CW while in Div. 3K more larger-sized crab were observed to have old carapace damage.

Generally, old leg loss increased with size up to about 40-50 mm and changed little at larger sizes. Incidence of leg loss was higher in St. Mary's Bay, particularly from the initial sets (sets 1-3), than from either Div. 2J or 3K across a broad size range of about 23-70 mm CW common to all samples (Fig. 28).

Incidence of new carapace damage was compared across the four trawling experiments executed in Div. 3K (Fig. 29). Only male crabs were compared and soft-shelled (shell condition 1) crabs were removed from the analysis to eliminate potential bias created by the higher proportions of soft-shelled crabs captured in the repeated tow path experiment (Fig. 25). Soft-shelled crabs are especially delicate and subject to damage and leg loss. Incidence of new carapace damage was low (<10%) at most sizes (Fig. 29) but was highest in smallest crabs. No statistical differences were apparent among the four trawling experiments and new carapace damage was not significantly higher in samples from either the added weight to footgear or repeated tow path experiments than from the commercial reference mode (Table 4).

New leg loss or damage by size was also compared for males only across the four trawling experiments executed in Div. 3K (Fig. 30). Again soft-shelled males were excluded from the analysis. This analysis showed that incidence of new leg loss in male crabs was highest in smallest crabs and decreased to a very low level from about 8-50 mm CW across all trawling experiments (Fig. 31). New leg loss or damage was overall highest from the repeat trawling experiment and it was significantly higher than that from the reference commercial fishing mode ($p<0.0001$, Table 4). It was not significantly higher from tows with additional weight added than it was from the reference commercial fishing mode. We focused on the comparison between the repeated tow path experiment and reference commercial fishing mode by limiting our comparison to the predominant group of crabs (both sexes) in the two samples (11-38 mm CW, Fig. 23 and 26)) for new hard-shelled crab only (shell condition 2) and refined our analysis to focus on the predominate group of crabs to include only new hard-shelled (shell 2) crabs, of both sexes, smaller than 39 mm CW. This refined comparison showed that the incidence of new leg loss from the repeated tow path experiment was between 3-30% higher by size (CW) than from the reference commercial trawling mode (Fig. 31).

New versus old leg loss or damage showed an inverse relationship with size, based on secondary trawl catches of males from research fishing mode (Fig. 32). New leg loss or damage was most prominent in smaller crabs while old leg loss/damage was most common in larger crabs. The new leg loss or damage incidence was initially high with 50-100% of the smallest crabs (5-10 mm CW) having these injuries. It declined to a negligible level at about 50-60 mm CW. Old leg loss was lowest (10-20%) in smallest crabs and increased with size to about 80% in 90-115 mm CW crabs. New vs. old carapace damage was also compared by size but no clear relationship was evident. Old leg loss increases with size because such injuries accumulate throughout life. New leg loss or damage decreases with increasing size because larger crabs are less delicate and less easily damaged within trawls.

POTENTIAL FOR DAMAGE AND INFERENCES FROM VARIOUS DATA SOURCES

Trends from fisheries and research surveys

Division 2J snow crab fishery catch rates (CPUE) from an area that has been closed to trawling (Fig. 7) were compared with catch rates outside the closed area (Fig. 33). There was very little difference in catch rates inside versus outside the closed area in recent years, suggesting that shrimp trawling has little impact on commercial snow crab mortality.

Division 2J fall multi-species bottom trawl surveys in 2004 showed an increase in biomass of pre-recruit (76-94 mm adolescent) snow crabs (Fig. 34) particularly in the north, around Cartwright Channel (about N54°75.00/ W56°.00.00). This increase in pre-recruits in 2004 was reflected in an increase in legal-sized crabs in 2005 around Cartwright Channel. This local increase in snow crab recruitment in northern Div. 2J occurred despite intense shrimp trawling in part of this area (Fig. 35). This increase did coincide with a decrease in snow crab fishing effort in Cartwright Channel after 2002 (Fig. 36).

In Div. 3K and Div. 3L, total snow crab by-catch in the large vessel shrimp fishery has remained at low levels (<300 kg annually) since 1995 (Fig. 37). In Div. 2J snow crab by-catch increased steadily from about 150 kg to 1400 kg during the period, 1995-2002 and has subsequently sharply declined to about 400 kg in 2004. By-catch rate has remained low at 1-2 kg per tow in most years (Fig. 37). Snow crab by-catch is recorded by observers to the nearest whole kg. Most by-catch records (87%) are of 1.0 kg (Fig. 38), and include many very small by-catches of <1.0 kg. Therefore individual by-catches as well as total by-catches are overestimated.

Results of earlier (unpublished) studies on spatial variation in snow crab leg loss show no clear association with shrimp trawling intensity. At-sea sampling by observers during the 2000 and 2001 fisheries (Fig. 19) suggested a higher incidence of large males with no legs lost in Div. 3L than in more heavily trawled Div. 2J and 3K, for old-shelled males. However, there was only a slight increase in incidence of large males with no legs lost from Div. 2J south to Div. 3L for new-shelled males. Data from the 2001 fall multi-species bottom trawl survey (Fig. 21) showed no indication of a higher incidence of intact crabs (0 leg loss) in Div. 3L when compared to Div. 2J or 3K for any male size group.

Spatial interaction between shrimp and snow crab fisheries

Snow crab commercial logbook data from 1995-2005 show that fishing effort was broadly distributed throughout inshore and offshore areas of Div. 2J3KL, and was highest in the inshore to mid-shore portions of Div. 3KL (Fig. 39). Shrimp fishery logbook and observer data showed that most of the shrimp fishing effort has occurred further north (Div. 2J3K) and offshore (Fig. 40) than most of the crab fishing effort. Shrimp trawling intensity has been greatest in offshore regions of the continental shelf and along the shelf edge.

The potential for non-catch (unaccounted) mortality or damage to snow crab by shrimp trawls was further considered by examining annual trends, by division, in fishing intensity and spatial distribution of shrimp and snow crab fisheries as well as the degree of spatial overlap between them (Fig. 41-43). In Div. 2J, snow crab fishing effort was relatively consistent over time, ranging from 1000 to 1400 sets per year from 1995 to 2004 (Fig. 41). Shrimp fishing effort ranged from 3157 to 5486 sets during 1995-2000 before rising sharply to 12,837 sets in 2002 and then declining sharply to about 7200 sets in 2004. The total area trawled (km^2, Fig. 41) by the Div. 2J shrimp fleet reflected the number of shrimp sets, rising from an initial low of 198 km^2 in 1995 to a peak of 1398 km^2 in 2002 and then declining to 1054 km^2 in 2004. Both the crab and the shrimp fisheries have expanded spatially during the past decade with area fished (number of cells, Fig. 41) approximately doubling between 1996 and 2001 for the shrimp fishery and between 2000 and 2004 for the crab fishery. The area of overlap between the two fisheries in Div. 2J peaked in 2002 at 164 cells (Fig. 41), representing 49% of the total area fished in the crab fishery.

Fishing effort in the Div. 3K shrimp fishery was very low prior to 2001 whereas snow crab fishing effort was variable. Effort in both fisheries increased to maxima of 27,653 sets for shrimp and 11,495 sets for crab in 2004 (Fig. 42). Total area trawled annually by the shrimp fleet reflected the trend in fishing sets, with a maximum of 2,064 km^2 trawled in 2004. The spatial distribution of crab fishing effort increased to a maximum of 1,126 cells in 2004 (Fig. 42). The area fished in the shrimp fishery expanded greatly from 27 cells in 2000 to 514 cells in 2001. It continued to spatially expand to 689 cells in 2004. Spatial overlap

between the two fisheries in Div. 3K was highest, at 320 cells, in 2003, representing 36% of the total area fished in the crab fishery

Shrimp fishing effort was lower in Div. 3L than in the more northern areas (Fig. 43), as the Div. 3L Canadian shrimp fishery (representing about 83% of the total international shrimp fishery) was limited to the nose of the Grand Bank. Shrimp fishing effort peaked in 2003 at 6,131 sets. Snow crab fishing effort increased from 3,757 sets in 1995 to 14297 sets in 2004. The total area trawled in Div. 3L increased from 9 km^2 in 1999 to peak at 446 km^2 in 2003 (Fig. 43). The snow crab fishery is prosecuted over a much greater area than is the shrimp fishery in Div. 3L (Fig. 39 and Fig. 40 respectively). The area fished by the crab fishery increased to a maximum of 1,067 cells in 2004 whereas the less expansive shrimp fishery was most broadly distributed, occupying 171 cells, in 2003. Spatial overlap between the two fisheries in Div. 3L was highest, at 23 cells, in 2002 and represented only 2.4% of the total area fished in the crab fishery.

An analysis of the extent to which each cell was trawled, or re-trawled, annually by the shrimp fleet within the period 1995-2004 was conducted by summing, for each year, trawl swept areas within each cell and dividing by the mean cell area. The distribution of annual areas trawled by cell was positively skewed, with a mode (819 observations) at 0.1% of individual cell areas being trawled in any year (Fig. 44). There were fifty-three year-specific observations of 2.0% of cell areas being trawled, with the highest single observation being 64% of a cell trawled in any year. The analysis of areas trawled within cells by year was refined by applying it to only those cells that were common to both fisheries. In each division (Fig. 45), less than 5% of the cell area was trawled in any year for most of the overlapped cells. Only about 1-50 cells (5–30% of total overlapping cells) had 5-15% of their area trawled and very few cells (none in Div. 3L) had more than 15% of their areas trawled in any given year.

DISCUSSION

MORTALITIES

At the St. Mary's Bay experimental sites, non-capture mortalities of snow crabs from trawling appear to be negligible. We observed no dead snow crab within our trawling corridors after trawling. However, Schwinghamer et al. (1998) did observe dead snow crabs in tow paths on the northern Grand Bank following trawling. This difference from our results may be due to the repeated trawling along a relatively narrow band of seabed (120-250 m) on the Grand Bank together with the harder substrate in the northern Grand Bank experiment (dense sand) relative to that in St. Mary's Bay (soft mud). Alaskan experiments showed no immediate mortality on red king crab (Rose 1999; Donaldson 1990) as a result of encounters with trawl footgear.

There was no consistent decrease in density of snow crabs from ROV video observations in our trawling corridors after trawling, despite the fact that our trawl caught and removed crabs from both corridors. In fact, we found an increase in snow crab density in the Outer-Bay trawling corridor the day after trawling. This is consistent with Prena et al. (1999), who noted an initial decline in snow crab catch rate during six successive trawl tows (10-12 hrs.) along an intensively trawled narrow corridor on the northern Grand Bank, followed by an increase in snow crab catch rate during 7 subsequent tows. The authors attributed the increase after tow 6 to an influx of pre-adult scavenging male crabs. The decrease in density following trawling in our Mid-Bay corridor was likely due to several interacting factors that included direct removal of some crabs during the trawling, poor visibility on the first day following trawling, and redistribution of initially intruding scavenging crabs by day 3-5 following trawling.

CARAPACE DAMAGE

Analyses of ROV video showed no crabs with damaged carapaces in our trawling corridors after trawling and we found a very low incidence of crabs with new carapace damage (about 2%) within our trawled samples in the St. Mary's Bay trawl corridors and our Div. 3K secondary trawl samples. Such new carapace damage may not be due to encountering trawl footgear, but could be due to damage incurred from the capture process.

It is possible that carapace damage can be lethal. Miller (1977) observed snow crabs in traps that had been entirely eaten (excluding the shell) by amphipods in seven days after sustaining injury. Damage and mortality to benthos from encounters with trawl gear components will be partly a function of bottom type with greater damage expected on hard bottoms. The soft mud bottom at the St. Mary's Bay sites may have been a significant factor in the absence of observable damage. Rose (1999) found that forces exerted by commercial footgear used to catch Alaskan king crab were rarely sufficient to crack a crab carapace.

LEG LOSS OR DAMAGE

Our ROV video observations within trawling corridors suggest about a 10% incidence of some limb loss in crabs as a result of encountering shrimp trawl rockhopper footgear. This increase was statistically significant for both trawling corridors, and may represent minimum estimates as only 45% and 58% of the seabed within the Outer-bay and Mid-bay trawling corridors, respectively, were trawled. Limb loss may also be underestimated in that scavenging crabs not exposed to trawling may have been included in the post–trawling ROV observations. There is some uncertainty in the Outer-Bay corridor results

associated with the lack of agreement between ROV pre-trawling incidence of leg loss and the incidence of old leg loss in trawl-caught samples. Uncertainty in the Mid-Bay corridor is associated with the necessity to reject the ROV video data from the day immediately following trawling due to poor visibility. Despite these uncertainties, our incidences of leg loss are consistent with those from similar experiments on red king crab in Alaska (Rose 1999; Donaldson 1990).

Our results from the trawling corridors are also consistent with our results on new leg loss from experiments with secondary trawls in Div. 3K. New leg loss in secondary trawls is largely attributable to post-capture damage within trawls. Rose (1999) observed only 3.5% injury rates for red king crab captured by secondary trawls, using a main trawl footrope that was suspended about 20 cm above the seafloor to minimize contact with the substrate and crabs. This low level of damage was attributed primarily to handling. Much higher levels of damage, especially new-leg loss, in our trawl experiments may be related to unknown differences in crab size and shell condition as well as the magnitude and composition of trawl total catches.

In the Div. 3K experimental studies with the secondary trawl attached underneath the main trawl, we found no significant increase in new leg loss even after additional weight was added to the main trawl footgear to enhance bottom contact. However, we did find a significantly higher incidence of new leg loss in the secondary trawl catches after a tow path had been repeatedly trawled (6 times), relative to our commercial reference mode. This increase in incidence of leg loss (of about 3-30%) was not due to differences in size or shell condition between samples. The reason for the high catch rate of small and soft-shelled crabs after repeat trawling, relative to the reference, is unknown. This could be due to disturbance, immigration of crab into the area, and increased catchability of small and soft-shelled crabs by repeat trawling, or it may reflect small-scale spatial variation in population demographics.

Our results on new leg loss imply a relatively high incidence of leg loss in shrimp fishing areas that should be reflected in accumulated old leg loss. However, we found a higher incidence of old leg loss in St Mary's Bay samples, where no trawling occurs, than in Div 2J and 3K, where shrimp fisheries are most heavily prosecuted. This suggests that while intense trawling leads to increased leg loss, trawling is not the primary cause of leg loss. Leg loss was highest from shallow water tows in St. Mary's Bay, implying that other factors may be more important. This agrees with our results from an earlier study (unpublished) that showed no clear differences in incidence of total leg loss between areas intensively trawled (Div 2J and 3K) versus a virtually untrawled area (Div. 3L), using multiple data sources.

The high incidence of accumulated old leg loss in large crabs generally indicates that some crabs survive such injuries, although Miller (1977) noted that limb loss or injury may be fatal to snow crabs as it could leave them vulnerable to

infestation by amphipods or diseases. It remains possible then that latent mortality resulting from leg loss may not be reflected by incidence of old leg loss. We showed however that recruitment recently increased in the Cartwright Channel area of Div. 2J while shrimp trawling continued in the area but snow crab fishing area had declined. This implies that discarding of crabs in the snow crab fishery may be a more important source of mortality than shrimp trawling.

FISHERIES INTERACTIONS

Snow crab bycatches in shrimp trawls were very low. There was no effect to snow crab biomass caused by actually catching crabs in the shrimp fishery.

The growth of both fisheries has led to increased interaction and overlap in recent years, especially in Div. 3K. From out trawling corridor experiments and repeat trawling experiments in Div. 3K we found that intense shrimp trawling is associated with increased incidence of leg loss. However the level of trawling on snow crab grounds is generally not intense. In Div. 2J3K 25-50% of the exploited crab grounds have overlapped with the shrimp fishery in any given year since 2000. In these areas of fisheries overlap, shrimp trawling intensity predominately remains low with ≤ 5% of an area being trawled by footgear in any given year. Therefore a maximum of about 3% (0.5 x 0.05= 0.025) of crab ground is trawled in any year within Div. 2J3K. Less than 2% of exploited crab grounds have overlapped with the shrimp fishery in Div. 3L.

Our estimates of area trawled are based only on footgear width. Other parts of the trawl in contact with bottom during shrimp trawling such as bridles, warps, and doors may increase the extent of trawling damage but any increase would likely be marginal. Gavaris and Black (personal communication) estimated that the footprint of the trawl doors is about $1/17^{th}$ that of the area of the footgear for Canadian groundfish vessels operating on George's Bank. They also estimated the areas covered by bridles to be three times as great as that of the footgear but Rose (1999) found red king crabs encountering the "sweeps" of trawls to be generally unharmed. The levels of damage (i.e. leg loss) we observed in our St. Mary's Bay trawling corridors would have included any damage induced by all trawl components.

From analysis of snow crab CPUE trends in the Div. 2J area of the Hawke Channel closed to bottom trawling, we found trends in commercial CPUE for snow crab inside the closed area to have been virtually identical to those from the remainder of Div. 2J, since closure was first imposed in 2003. The closed area has had no impact on commercial catch rates in Div. 2J, consistent with the findings of Armstrong et al. (1991) for an Alaskan red king crab fishing area closed to trawling, where no significant changes in abundance of female and pre-recruit crab were found before versus after cessation of trawling. We found that the recent increase in Div. 2J CPUE occurred predominately as a result of a

recruitment and biomass increase in the Cartwright Channel, an area where snow crab fishing effort has declined but shrimp fishing effort persists. This suggests that crab fishing practices (e.g. handling and releasing pre-recruits) may have a greater adverse effect on snow crab biomass than does shrimp trawling.

CONCLUSIONS AND RECOMMENDATIONS

Our experiments failed to show any direct effect of trawling on snow crab mortality or carapace damage. They did strongly suggest that intense trawling, at levels considerably higher than those imposed by the commercial shrimp fishery, could cause increased leg loss in the order of about 10%. Broad spatial comparisons indicate that areas exploited by the shrimp fishery are not associated with relatively high incidence of leg loss, and that other factors such as predation or handling practices in the snow crab fishery may have a greater effect on leg loss and mortality. Other fishery and survey data also support our conclusion that the shrimp fishery does not impose a substantial mortality on snow crab.

While our conclusions are well supported by results from multiple, diverse approaches and datasets, our direct observations of snow crab encounters with trawls were quite limited. We recommend further studies based on direct observation of crab encounters with trawls, to document crab behavior (reaction to trawls) and describe mechanisms for avoiding damage. We also recommend that crab catch rates and physical damage continue to be monitored within areas closed to trawling and compared with comparable data from nearby areas open to trawling to detect any long-term effect of trawling on snow crab mortality. Studies of effects of leg loss on latent snow crab mortality would also be highly relevant.

Despite the fact that studies to date indicate little effect on the snow crab resource from shrimp trawling, we recommend that effort be devoted to research into mobile bottom fishing technologies that minimize or eliminate bottom contact.

ACKNOWLEDGMENTS

We thank the many colleagues who contributed their expertise and effort in various capacities to make this project a success. We especially thank Capt. Don Randell and crew of the research vessel *CCGS Shamook*, as well as Albert Mullowney of the Canadian Coast Guard for their outstanding at-sea and shore-based support of the St. Mary's Bay trawling experiments. We acknowledge Pro-Dive Marine Services (Mike Smith, Jason Galvin, and Doc Smith) for providing and skillfully operating the ROV and related technology. We also acknowledge Century Sub-Sea (Jeff Aitkin, Kirk Stead) for providing navigational support for

the St. Mary's Bay experiments. We thank James and Matthew Corcoran and crew of the commercial vessel *Coot's Pond Osprey* for conducting the trap sampling in St. Mary's Bay. Aubrey Russell and the crew of the *Shandy Pauline II* as well as Anthony Penton and the crew of the *Krista Paul* are acknowledged for their diligent support of the trawling work with secondary trawls in Div. 2J and 3K respectively. The efforts of observers Dennis Rice and Colin Hart, who participated in the Div. 2J3K trawling experiments are appreciated. We thank George McGuire, Jerry Brothers and Rick Stead for their assistance with contracting outside sources of expertise. Others who participated in some way include Don Stansbury, Paul Higdon, Todd Paddle, Elaine Hynick, and Paul O'Keefe. This project was funded by Fisheries Management Branch, Fisheries and Oceans Canada, NL Region.

REFERENCES

Armstrong, D.A., Wainwright, T.C., Jensen, G.C., Dinnel, P.A., and Andersen, H.B. 1993. Taking refuge from bycatch issues: red king crab (*Paralithodes camtschaticus*) and trawl fisheries in the eastern Bering Sea. Can. J: Fish. Aquat. Sci. 50: 1993-2000.

Dawe, E.G., McCallum, B.R., Walsh, S.J., Beck, P.C., Drew, H.J., and Seward, E.M. 2002. A study of the catchability of snow crab by the Campelen 1800 survey trawl. DFO Can. Sci. Advis. Sec. Rep. 2002/051.

Dawe, E.G., Drew, H.J., Veitch, P.J., Turpin, R, Seward, E., and Beck, P.C. 2003. An assessment of Newfounland and Labrador snow crab in 2002. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/025.

Dawe, E.G., Mullowney, D., Stansbury, D., Parsons, D.G., Taylor, D.M., Drew, H.J., Veitch, P.J., Hynick, E., Skanes, K., O'Keefe, P.G., and Beck, P.C. 2006. An assessment of Newfoundland and Labrador snow crab in 2005. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/031.

Dew, C.B., and McConnaughey, R.A. 2005. Did trawling on the brood stock contribute to the collapse of Alaska's king crab? Ecol. Appl. 15(3): 919-941

DFO. 2005. Stock Assessment Report on Divisions 0B-3K Northern Shrimp. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2005/025.

Donaldson, W.E. 1990. Determination of experimentally induced non-observable mortality on red king crab. Alaska Dept. Fish and Game Regional Information Report 4K90-13 (Kodiak). 27 pp.

Kulka, D.W., and Pitcher, D.A. 2001. Spatial and temporal patterns in trawling activity in the Canadian Atlantic and Pacific. ICES CM 2001/R:02.

Miller, R.J. 1977. Resource underutilization in a spider crab industry. Fisheries, Vol. 2, No. 3: 9-13.

Prena, J., Schwinghamer, P., Rowell, T.W., Gordon, D.C. Jr., Gilkinson ,K.D., Vass. W.P., and McKeown, D.L. 1999. Experimental otter trawling on a sandy bottom ecosystem of the Grand Banks of Newfoundland: analysis of trawl bycatch and effects on epifauna. Mar. Ecol. Prog. Ser .181: 107-124.

Rose, C.S. 1999. What proportion of red king crab (*Paralithodes camtschaticus*) were injured by passage under bottom trawl footropes? ICES WGFTFB Meeting St. John's, Newfoundland, Canada, April 19–23, 1999.

Schwinghamer, P., Gordon, D.C. Jr., Rowell, T.W., Prena, J., McKeown, D.L., Sonnichsen, G., and Guigné, J.Y. 1998. Effects of experimental otter trawling on surficial sediment properties of a sandy bottom ecosystem on the Grand Banks of Newfoundland. Conserv. Biol. 12: 1215-1222.

Table 1. Sample and catch sizes (numbers of crab) for St. Mary's Bay trapping, trawling, and ROV experiments; SM=small-meshed, LM=large-meshed

Bay	Sex	Shell	Pre-Traps (SM)	Pre-Traps (LM)	Trawl (sampled)	Trawl (caught)	Post-Traps (SM)	Post-Traps (LM)
Outer	M	All	353	820	891	1306	300	611
		1	0	0	141	190	0	0
		2	19	5	588	923	7	8
		3	334	814	160	183	293	603
		9	0	0	2	10	0	0
	F	All	19	0	763	1270	27	1
		1	0	0	46	59	0	0
		2	18	0	702	1196	26	1
		3	1	0	0	0	1	0
		9	0	0	15	15	0	0
Mid	M	All	No Pre-trawl trapping in mid-bay corridor		718	1081	325	661
		1			212	306	3	1
		2			320	469	0	1
		3			183	302	322	659
		9			3	4	0	0
	F	All			190	301	2	0
		1			22	25	0	0
		2			164	272	1	0
		3			1	1	1	0
		9			3	3	0	0

Bay	Pre-Rov	Post-Rov
Outer	72	239
Mid	345	294 (all)
		42 (after 1)
		166 (after 2)
		85 (after 3)

Table 2. Statistical analysis (Fisher's Exact Test) of St. Mary's Bay ROV survey data, before vs after trawling video observations on whole crabs (no legs lost), df =1.

Fishers Exact Test (right-tailed) - All Crab		
Area	p	n
Outer Bay	0.0213	311
Mid Bay	0.0629	639
Mid Bay (After 2,3)	0.0115	597

Table 3. Sample and catch sizes (numbers of crab) for NAFO Division 2J3K trawling experiments using secondary trawls (retainer bags).

Div.	Trawl Portion	Sampling	Commercial Trawl	Weighted Trawl	Repeated Tow Path	Research Mode	Total
3K	Retainer Bag	Sampled	1731	4241	614	1940	8526
		Caught	1787	4713	1533	2381	10414
		% Sampled	96.87	89.99	40.05	81.48	81.87
	Main Trawl	Sampled		15		43	58
		Caught		15		43	58
		% Sampled		100		100	100
2J	Retainer Bag	Sampled	910				910
		Caught	910				910
		% Sampled	100				100

Table 4. Statistical analysis (Fisher's Exact Test) of NAFO Division 3K trawling experiments for leg loss in males, with soft-shelled males removed from the analysis, df =1.

Fishers Exact Test (right-tailed) - New Leg Loss/Damage: Ctrl. vs. Experimental		
Area	p	n
Add Weight	0.869	2565
Repeat Path	<0.0001	1332
Fishers Exact Test (right-tailed) - New Carapace Damage: Ctrl. vs. Experimental		
Area	p	n
Add Weight	0.8886	2547
Repeat Path	0.9663	1327

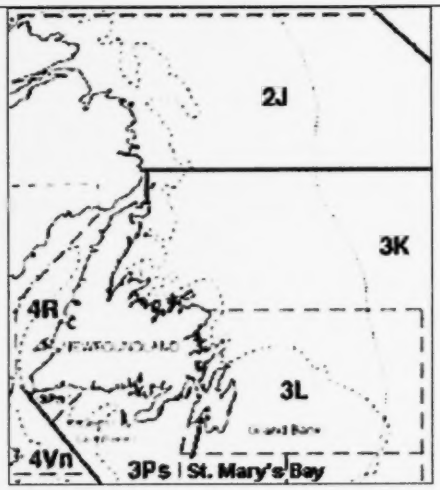

Figure 1. Map of NAFO Division 2J3KL inside (grey) vs. outside (white) the 200 m limit, showing location of St. Mary's Bay.

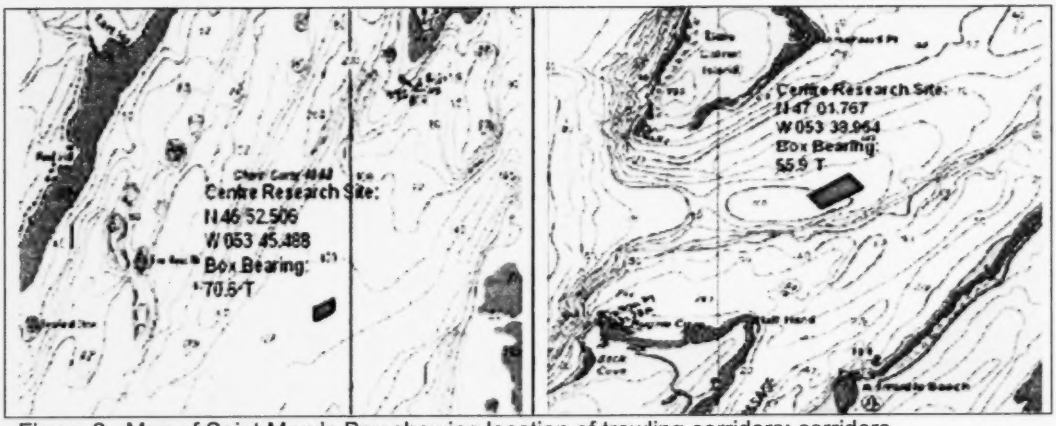

Figure 2. Map of Saint Mary's Bay showing location of trawling corridors; corridors.

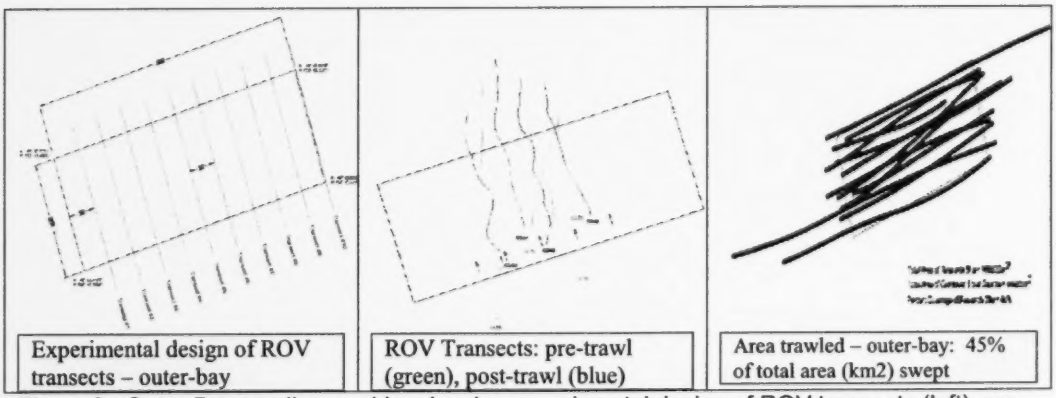
Experimental design of ROV transects – outer-bay
ROV Transects: pre-trawl (green), post-trawl (blue)
Area trawled – outer-bay: 45% of total area (km2) swept

Figure 3. Outer-Bay trawling corridor showing experimental design of ROV transects (left), pre-trawl and post-trawl ROV transects (center), and area covered by trawling (right).

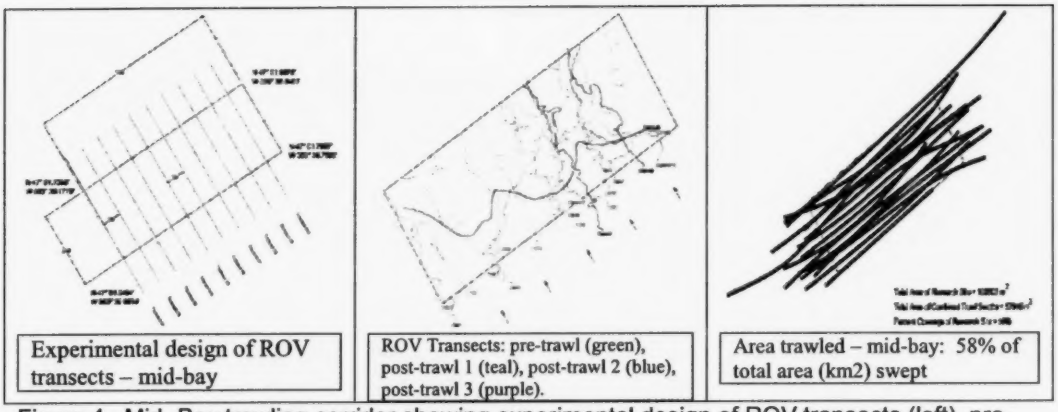
Experimental design of ROV transects – mid-bay
ROV Transects: pre-trawl (green), post-trawl 1 (teal), post-trawl 2 (blue), post-trawl 3 (purple).
Area trawled – mid-bay: 58% of total area (km2) swept

Figure 4. Mid- Bay trawling corridor showing experimental design of ROV transects (left), pre-trawl and post-trawl ROV transects (center), and areas covered by trawling (right).

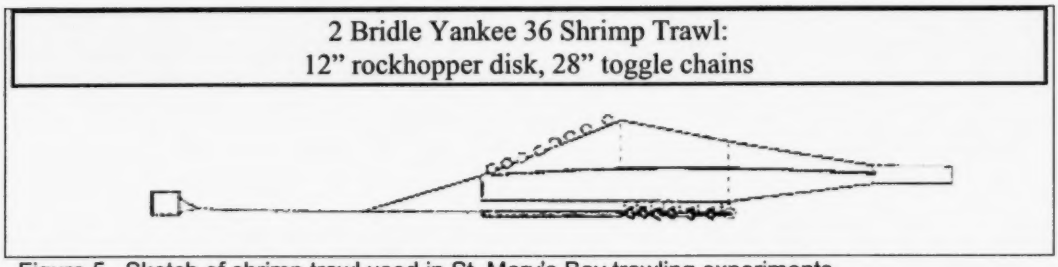

Figure 5. Sketch of shrimp trawl used in St. Mary's Bay trawling experiments.

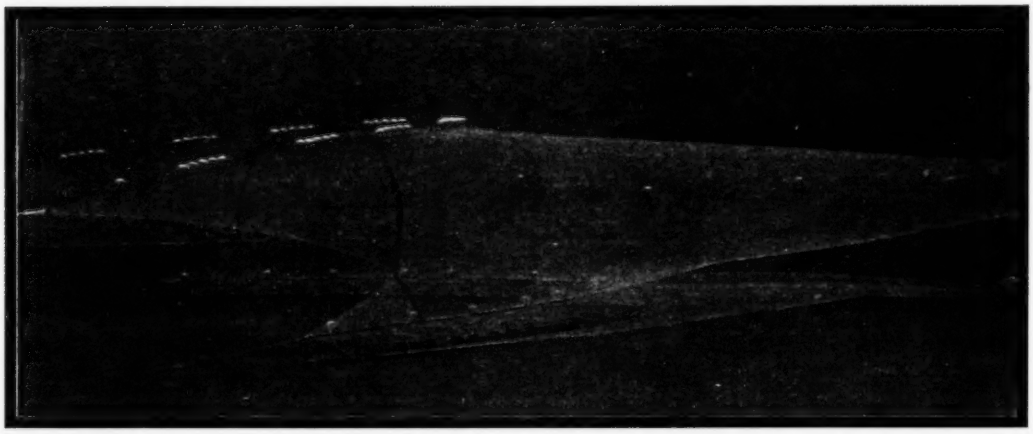

Figure 6. Model of IMP 920 commercial shrimp trawl with secondary trawl attached, used in Division 2J and 3K trawling experiments.

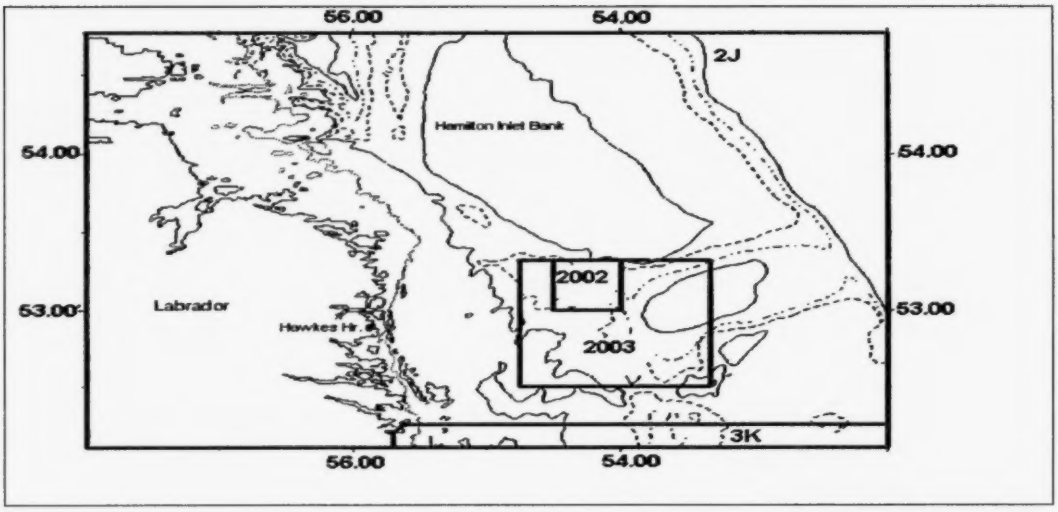

Figure 7. Map of NAFO Division 2J depicting the Hawke Channel area closed to bottom-trawling in 2002 and the expanded area closed since 2003.

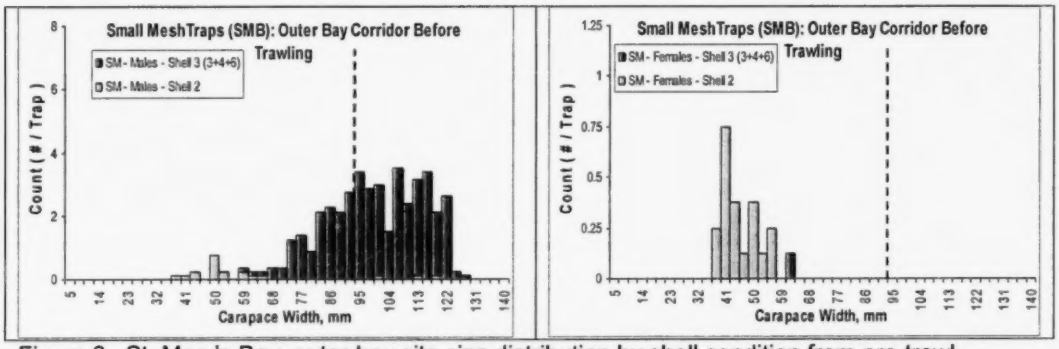
Small MeshTraps (SMB): Outer Bay Corridor Before Trawling
SM - Males - Shell 3 (3+4+6)
SM - Males - Shell 2
Count (# / Trap)
Carapace Width, mm
Small MeshTraps (SMB): Outer Bay Corridor Before Trawling
SM - Females - Shell 3 (3+4+6)
SM - Females - Shell 2
Count (# / Trap)
Carapace Width, mm

Figure 8. St. Mary's Bay, outer-bay site size distribution by shell condition from pre-trawl trapping using small-mesh traps for males (left) vs. females (right).

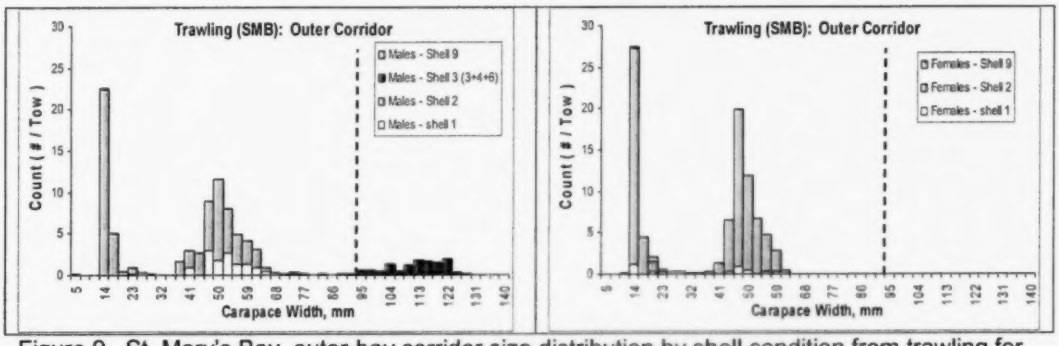
Trawling (SMB): Outer Corridor
Males - Shell 9
Males - Shell 3 (3+4+6)
Males - Shell 2
Males - shell 1
Count (# / Tow)
Carapace Width, mm
Trawling (SMB): Outer Corridor
Females - Shell 9
Females - Shell 2
Females - shell 1
Count (# / Tow)
Carapace Width, mm

Figure 9. St. Mary's Bay, outer-bay corridor size distribution by shell condition from trawling for males (left) vs. females (right).

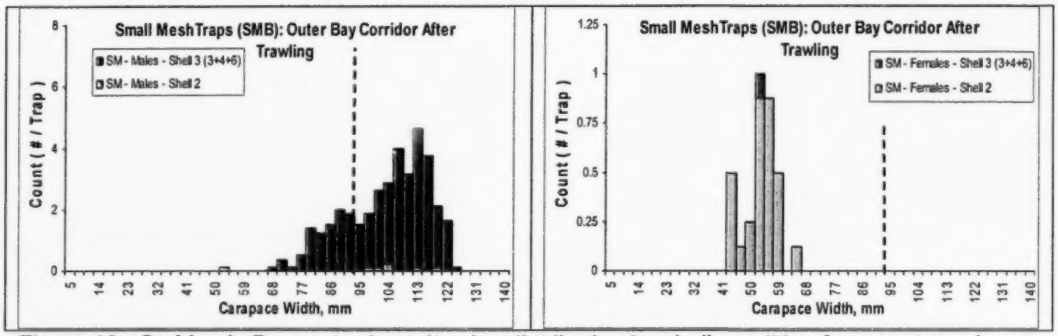
Small MeshTraps (SMB): Outer Bay Corridor After Trawling
SM - Males - Shell 3 (3+4+6)
SM - Males - Shell 2
Count (# / Trap)
Carapace Width, mm
Small MeshTraps (SMB): Outer Bay Corridor After Trawling
SM - Females - Shell 3 (3+4+6)
SM - Females - Shell 2
Count (# / Trap)
Carapace Width, mm

Figure 10. St. Mary's Bay, outer-bay site size distribution by shell condition from post-trawl trapping using small-mesh traps for males (left) vs. females (right).

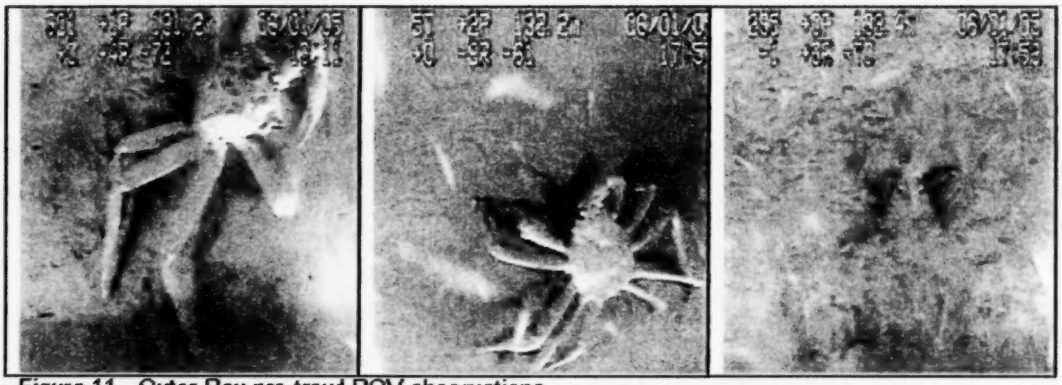

Figure 11. Outer-Bay pre-trawl ROV observations.

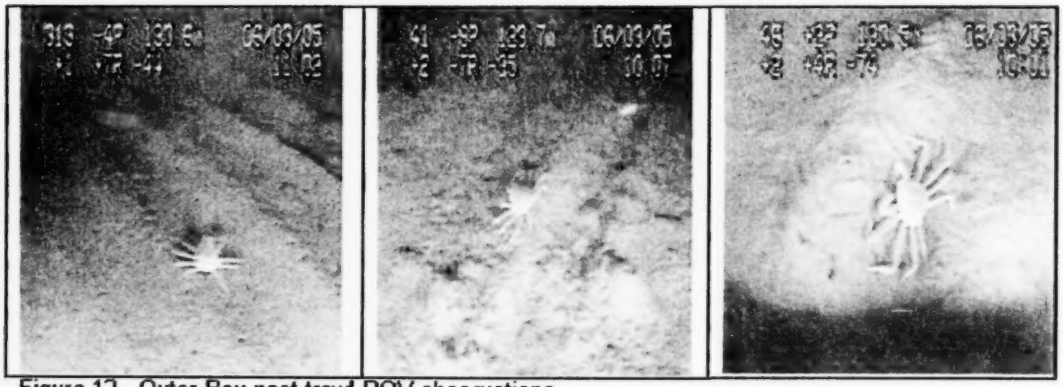

Figure 12. Outer-Bay post-trawl ROV observations.

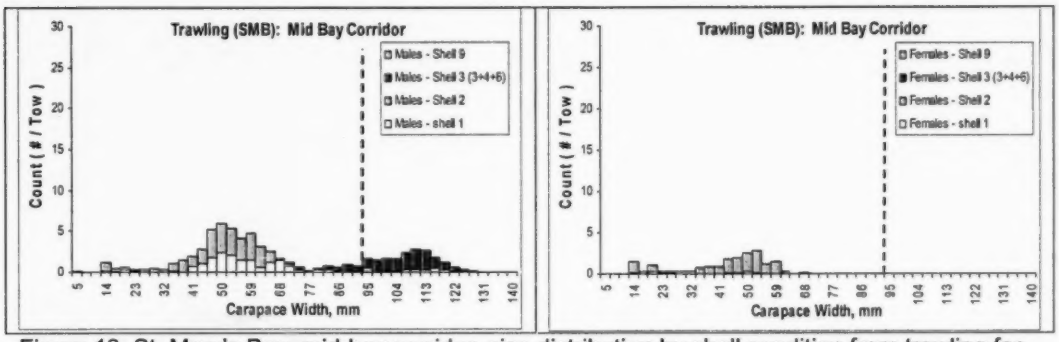
Trawling (SMB): Mid Bay Corridor
Males - Shell 9
Males - Shell 3 (3+4+6)
Males - Shell 2
Males - shell 1
Count (# / Tow)
Carapace Width, mm
Trawling (SMB): Mid Bay Corridor
Females - Shell 9
Females - Shell 3 (3+4+6)
Females - Shell 2
Females - shell 1
Count (# / Tow)
Carapace Width, mm

Figure 13. St. Mary's Bay, mid-bay corridor size distribution by shell condition from trawling for males (left) vs. females (right).

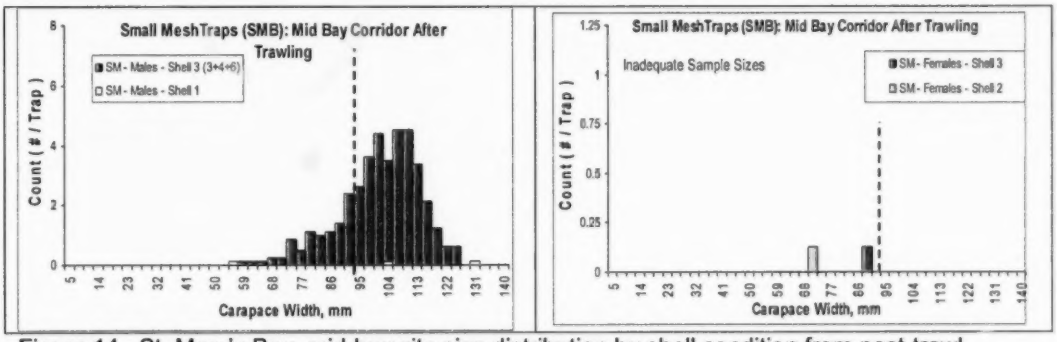
Small MeshTraps (SMB): Mid Bay Corridor After Trawling
SM - Males - Shell 3 (3+4+6)
SM - Males - Shell 1
Count (# / Trap)
Carapace Width, mm
Small MeshTraps (SMB): Mid Bay Corridor After Trawling
Inadequate Sample Sizes
SM - Females - Shell 3
SM - Females - Shell 2
Count (# / Trap)
Carapace Width, mm

Figure 14. St. Mary's Bay, mid-bay site size distribution by shell condition from post-trawl trapping using small-mesh traps for males (left) vs. females (right).

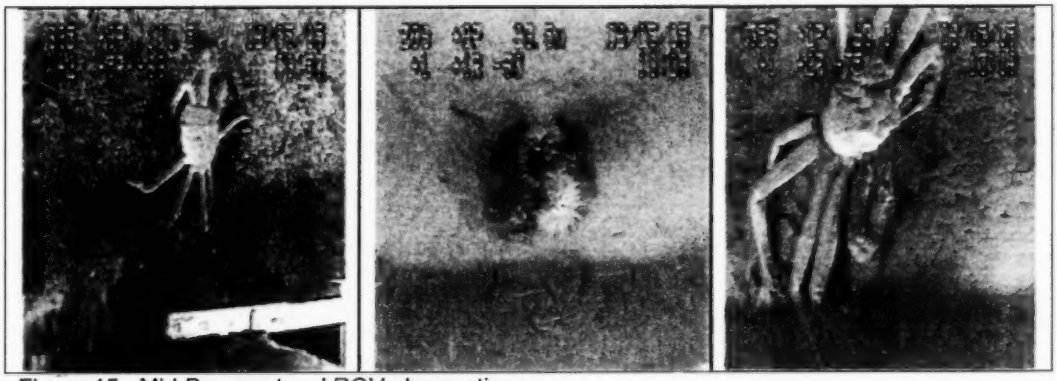

Figure 15. Mid-Bay pre-trawl ROV observations.

Figure 16. Mid-Bay corridor post-trawl ROV observations. Observations on day 1 post trawling (far left) reflect poor visibility due to turbid conditions.

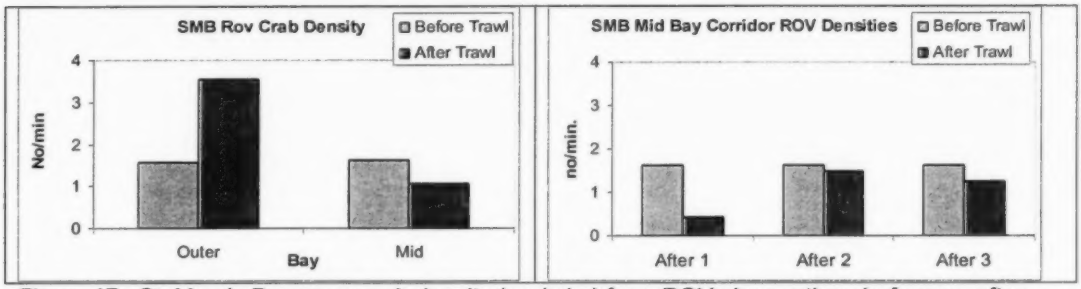

Figure 17. St. Mary's Bay snow crab density (no./min.) from ROV observations before vs. after trawling. Outer and mid-bay corridors (left panel) vs. mid-bay corridor for 3 separate post-trawl ROV surveys (right panel).

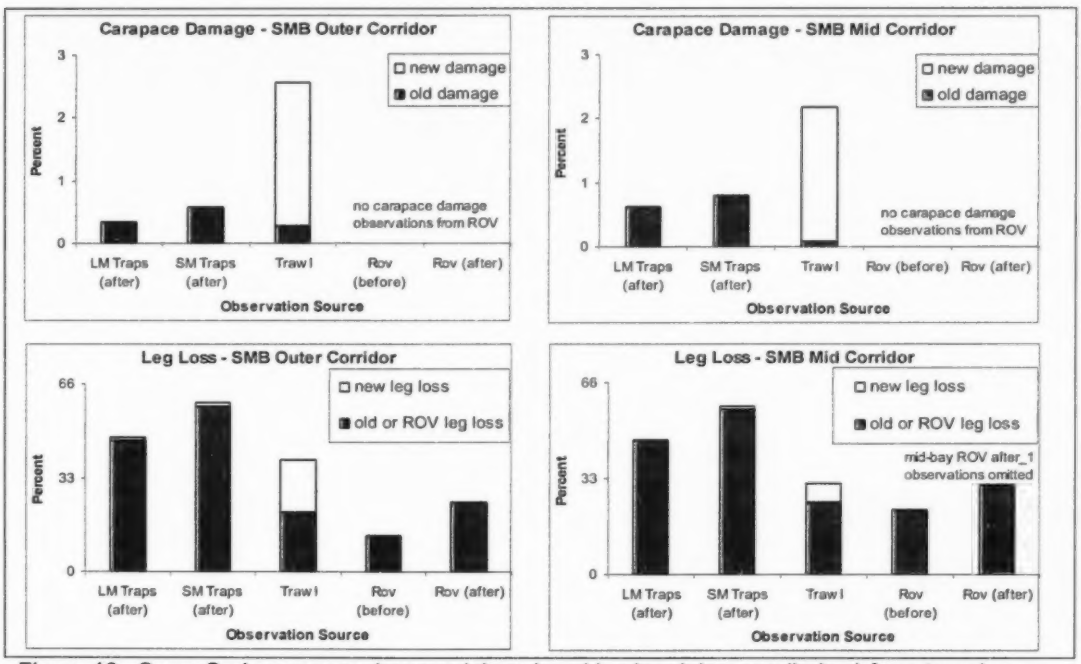

Figure 18. Snow Crab carapace damage (above) and leg loss/ damage (below) from trapping, trawling, and ROV observations in the St. Mary's Bay Outer-Bay corridor (left) vs. Mid-Bay corridor (right).

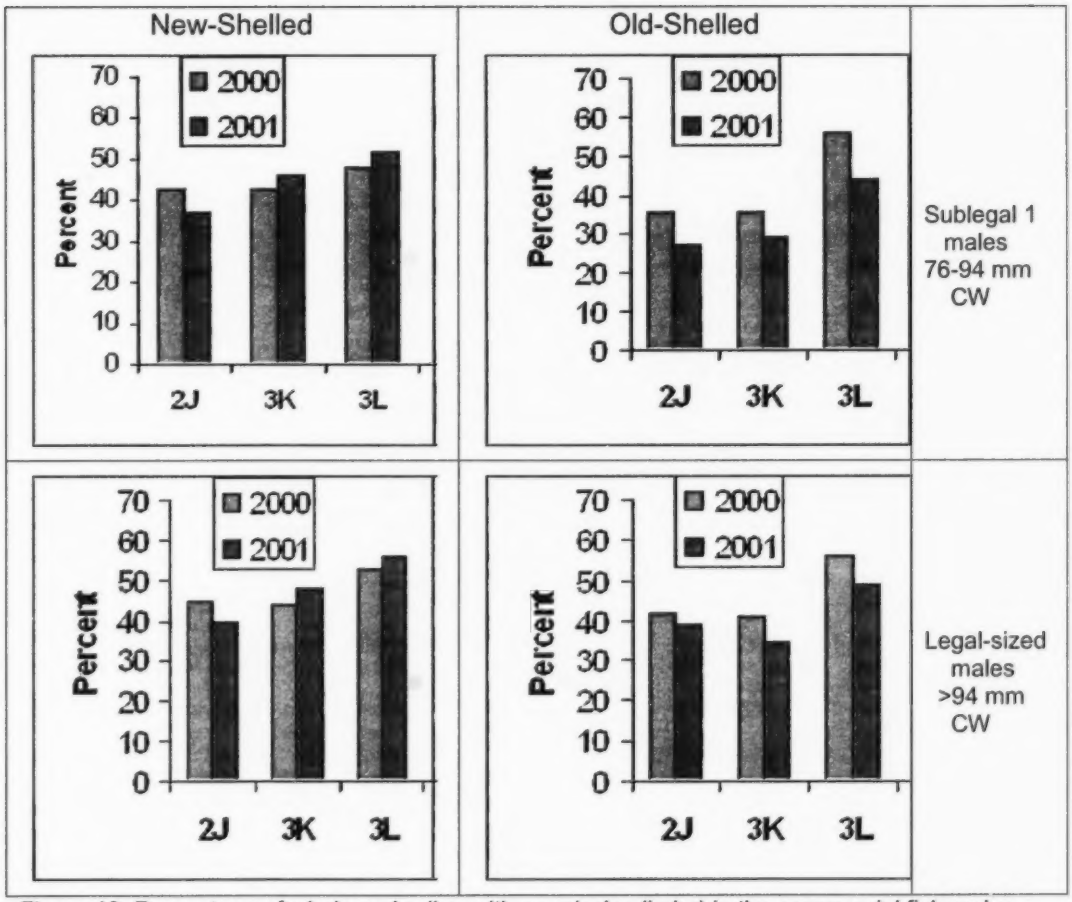

Figure 19. Percentage of whole crabs (i.e. with no missing limbs) in the commercial fishery by NAFO Division in 2000-2001for sublegal-sized (above) and legal-sized males (below) and for new-shelled (left) versus old-shelled males (right) from at-sea sampling by observers.

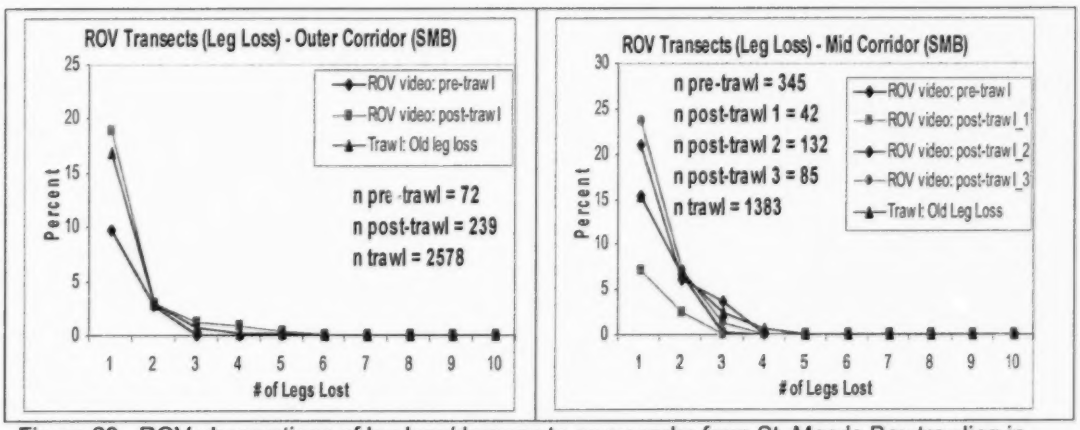
ROV Transects (Leg Loss) - Outer Corridor (SMB)
ROV video: pre-trawl
ROV video: post-trawl
Trawl: Old leg loss
n pre-trawl = 72
n post-trawl = 239
n trawl = 2578
Percent
# of Legs Lost
ROV Transects (Leg Loss) - Mid Corridor (SMB)
n pre-trawl = 345
n post-trawl 1 = 42
n post-trawl 2 = 132
n post-trawl 3 = 85
n trawl = 1383
ROV video: post-trawl_1
ROV video: post-trawl_2
ROV video: post-trawl_3
Trawl: Old Leg Loss

Figure 20. ROV observations of leg loss/damage to snow crabs from St. Mary's Bay trawling in outer-bay (left panel) and mid-bay (right panel) corridors contrasted against old leg loss from the trawl (control).

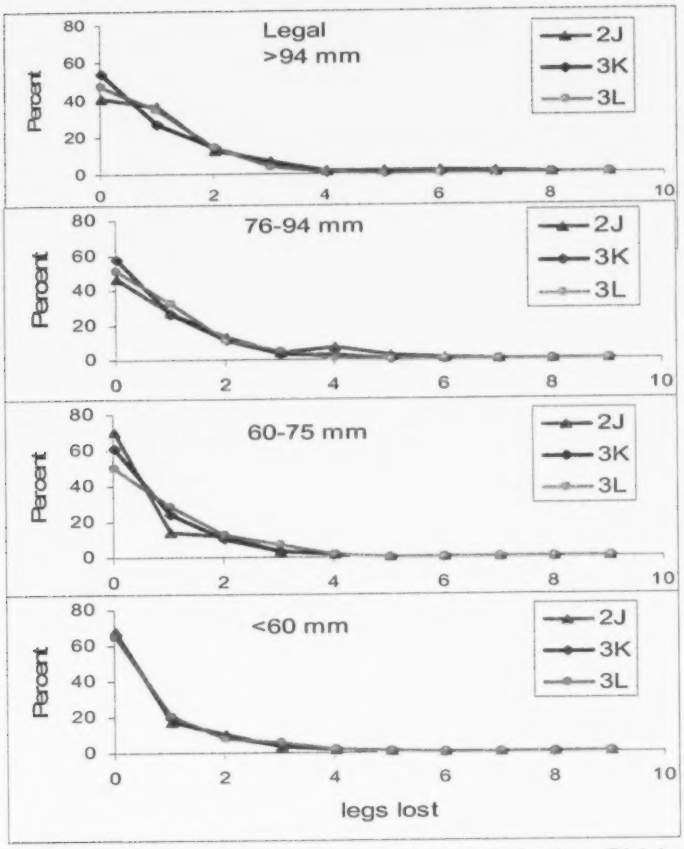

Figure 21. Percentage of snow crabs by number of missing limbs from Division 2J3KL 2000 fall multi-species bottom trawl survey by NAFO Division and male size group.

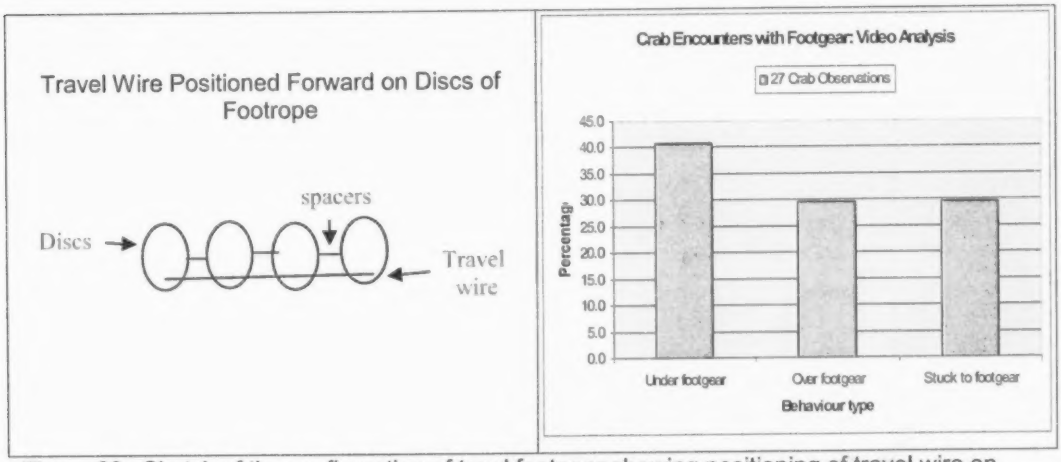

Figure 22. Sketch of the configuration of trawl footgear showing positioning of travel wire on footgear (left) and results of snow crab encounters with footgear from video analysis (right).

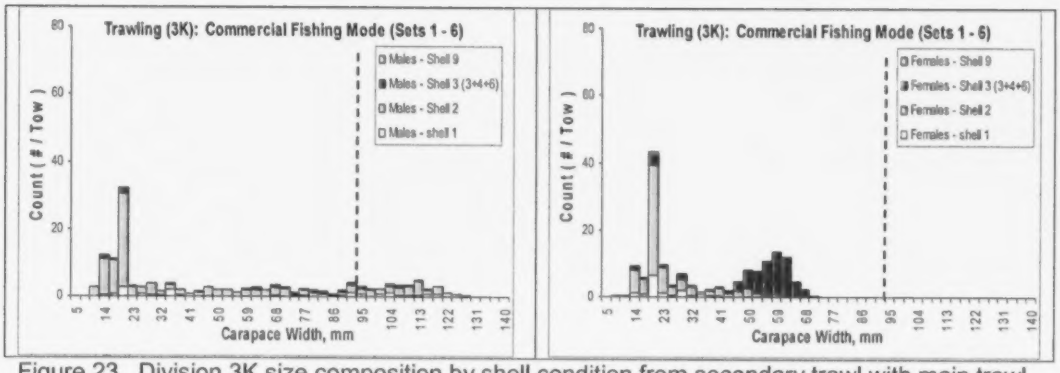
Trawling (3K): Commercial Fishing Mode (Sets 1 - 6)
Count (# / Tow)
Carapace Width, mm
Males - Shell 9
Males - Shell 3 (3+4+6)
Males - Shell 2
Males - shell 1
Trawling (3K): Commercial Fishing Mode (Sets 1 - 6)
Count (# / Tow)
Carapace Width, mm
Females - Shell 9
Females - Shell 3 (3+4+6)
Females - Shell 2
Females - shell 1

Figure 23. Division 3K size composition by shell condition from secondary trawl with main trawl configured in reference commercial trawling mode, for males (left) vs. females (right).

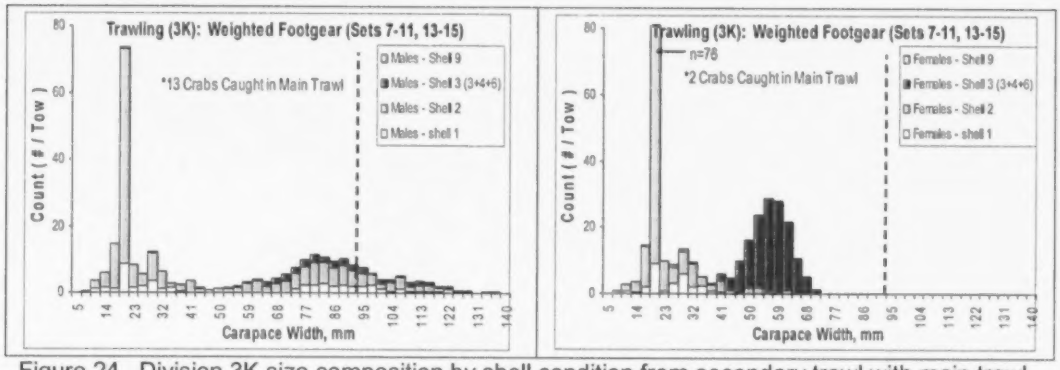
Trawling (3K): Weighted Footgear (Sets 7-11, 13-15)
*13 Crabs Caught in Main Trawl
Count (# / Tow)
Carapace Width, mm
Males - Shell 9
Males - Shell 3 (3+4+6)
Males - Shell 2
Males - shell 1
Trawling (3K): Weighted Footgear (Sets 7-11, 13-15)
n=76
*2 Crabs Caught in Main Trawl
Count (# / Tow)
Carapace Width, mm
Females - Shell 9
Females - Shell 3 (3+4+6)
Females - Shell 2
Females - shell 1

Figure 24. Division 3K size composition by shell condition from secondary trawl with main trawl configured in commercial trawling mode and additional weight on footgear, for males (left) vs. females (right).

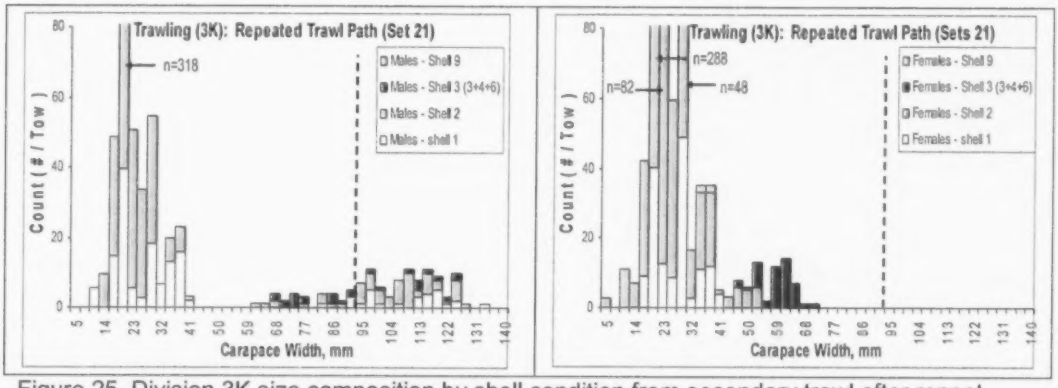

Figure 25. Division 3K size composition by shell condition from secondary trawl after repeat trawling of a tow path with crabs collected on sixth tow, for males (left) vs. females (right).

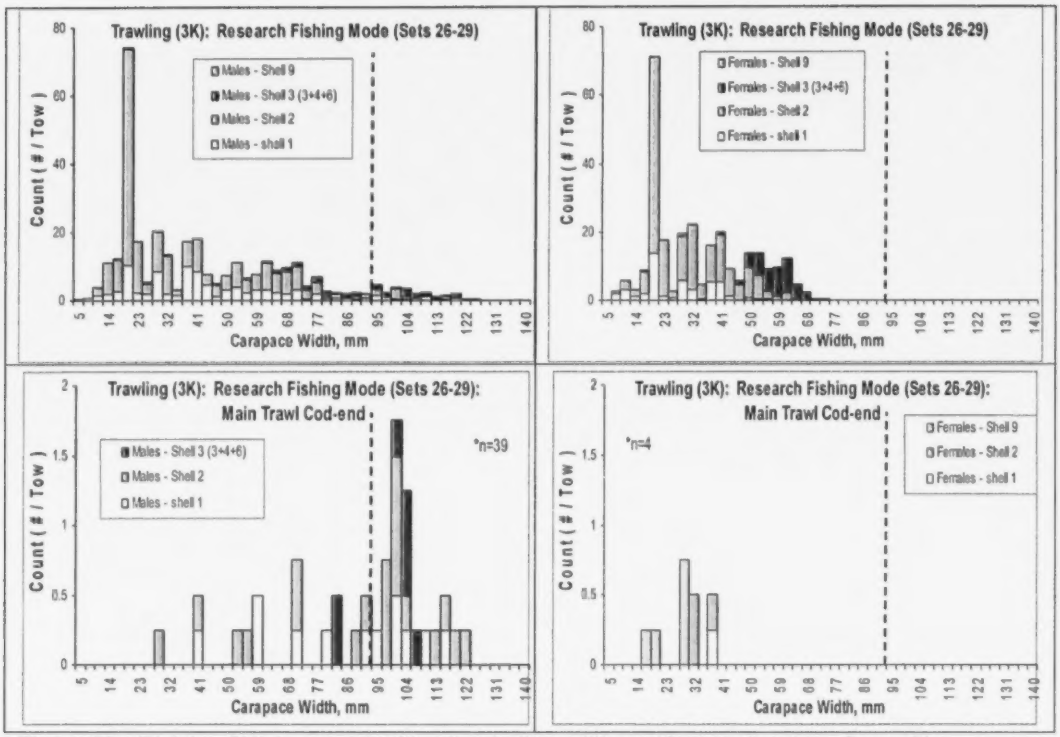
Trawling (3K): Research Fishing Mode (Sets 26-29)
Males - Shell 9
Males - Shell 3 (3+4+6)
Males - Shell 2
Males - shell 1
Count (# / Tow)
Carapace Width, mm
Trawling (3K): Research Fishing Mode (Sets 26-29)
Females - Shell 9
Females - Shell 3 (3+4+6)
Females - Shell 2
Females - shell 1
Count (# / Tow)
Carapace Width, mm
Trawling (3K): Research Fishing Mode (Sets 26-29):
Main Trawl Cod-end
Males - Shell 3 (3+4+6)
Males - Shell 2
Males - shell 1
*n=39
Count (# / Tow)
Carapace Width, mm
Trawling (3K): Research Fishing Mode (Sets 26-29):
Main Trawl Cod-end
*n=4
Females - Shell 9
Females - Shell 2
Females - shell 1
Count (# / Tow)
Carapace Width, mm

Figure 26. Division 3K size composition by shell condition with main trawl configured in research trawling mode. Samples are from secondary trawl (top panels) vs. main trawl (lower panels) for males (left) vs. females (right).

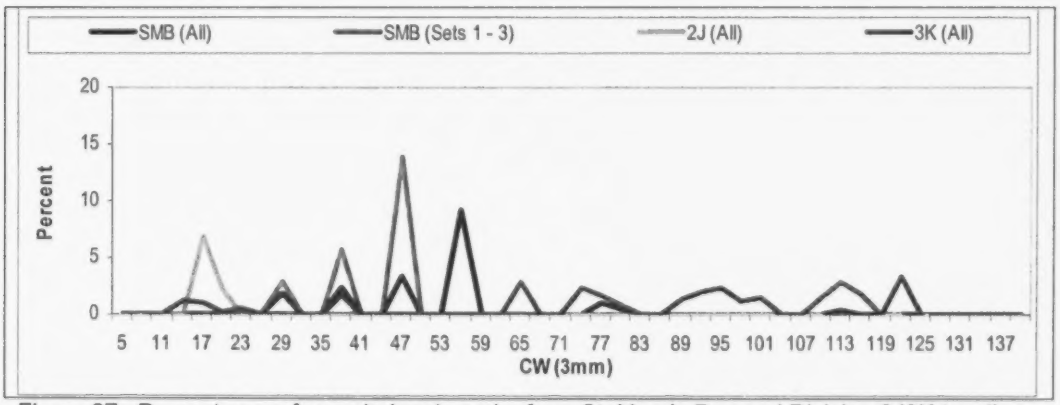

Figure 27. Percentages of sampled male crabs from St. Mary's Bay and Division 2J3K trawling experiments with old carapace damage.

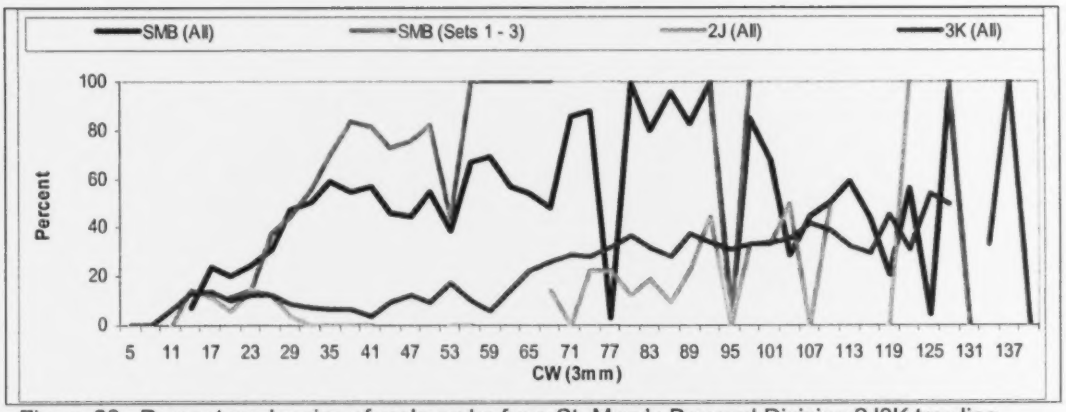

Figure 28. Percentage by size of male crabs from St. Mary's Bay and Division 2J3K trawling experiments with old leg loss/damage.

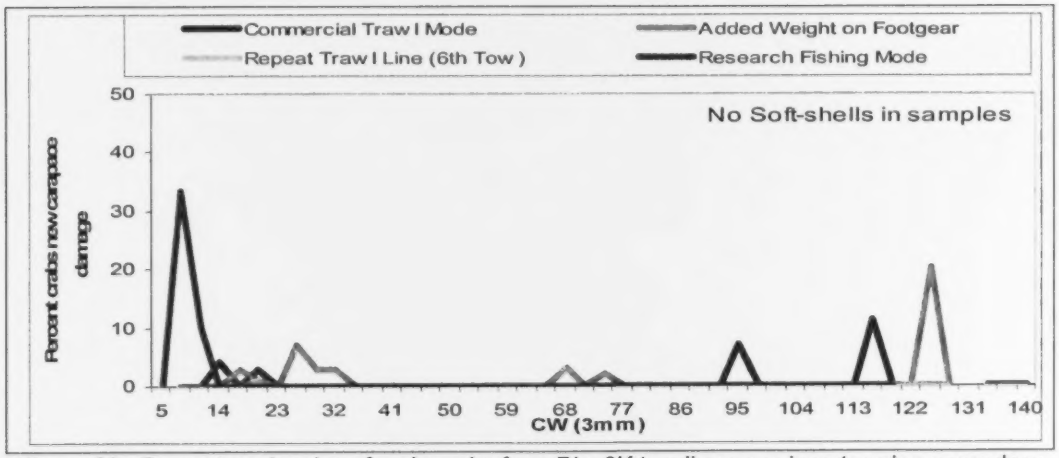

Figure 29. Percentage by size of male crabs from Div. 3K trawling experiments using secondary trawls with new carapace damage. Soft-shelled crab (shell type 1) not included.

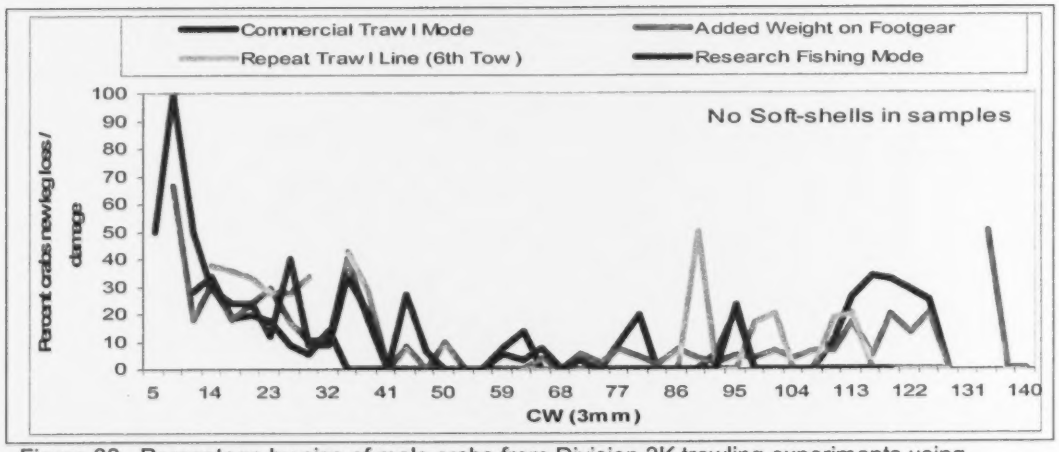

Figure 30. Percentage by size of male crabs from Division 3K trawling experiments using secondary trawls with new leg loss/damage. Soft-shelled crab (shell type 1) not included.

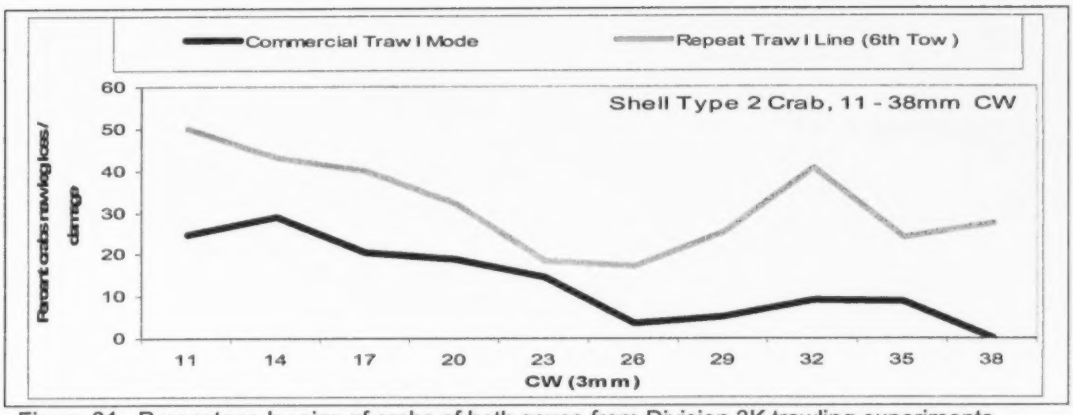

Figure 31. Percentage by size of crabs of both sexes from Division 3K trawling experiments using secondary trawls (reference commercial trawling mode vs. repeat trawling) with new leg loss or new leg damage.

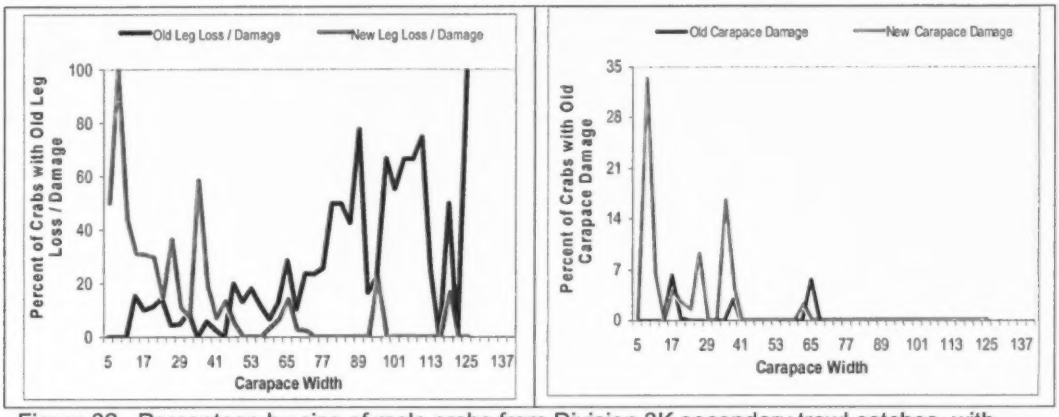
Old Leg Loss / Damage
New Leg Loss / Damage
Percent of Crabs with Old Leg Loss / Damage
Carapace Width
Old Carapace Damage
New Carapace Damage
Percent of Crabs with Old Carapace Damage
Carapace Width

Figure 32. Percentage by size of male crabs from Division 3K secondary trawl catches, with main trawl configured in research fishing mode, exhibiting new vs. old leg loss/damage (left panel) and new vs old carapace damage (right panel).

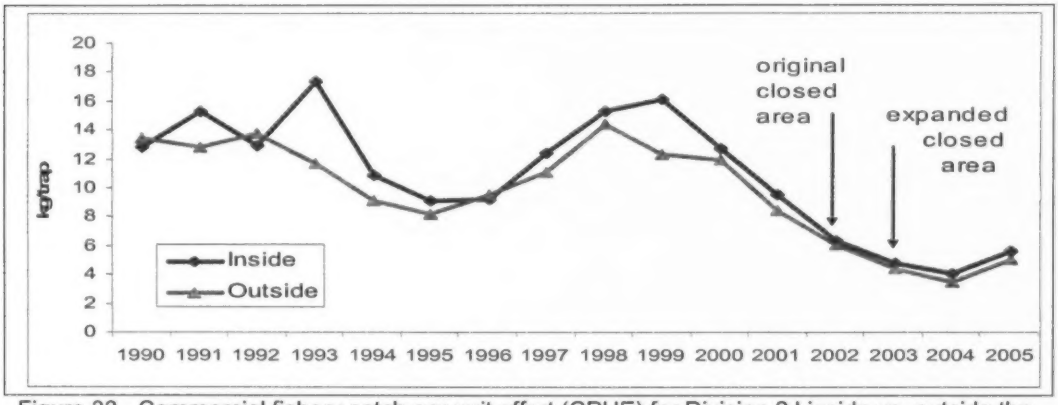

Figure 33. Commercial fishery catch per unit effort (CPUE) for Division 2J inside vs. outside the Hawke Channel closed area.

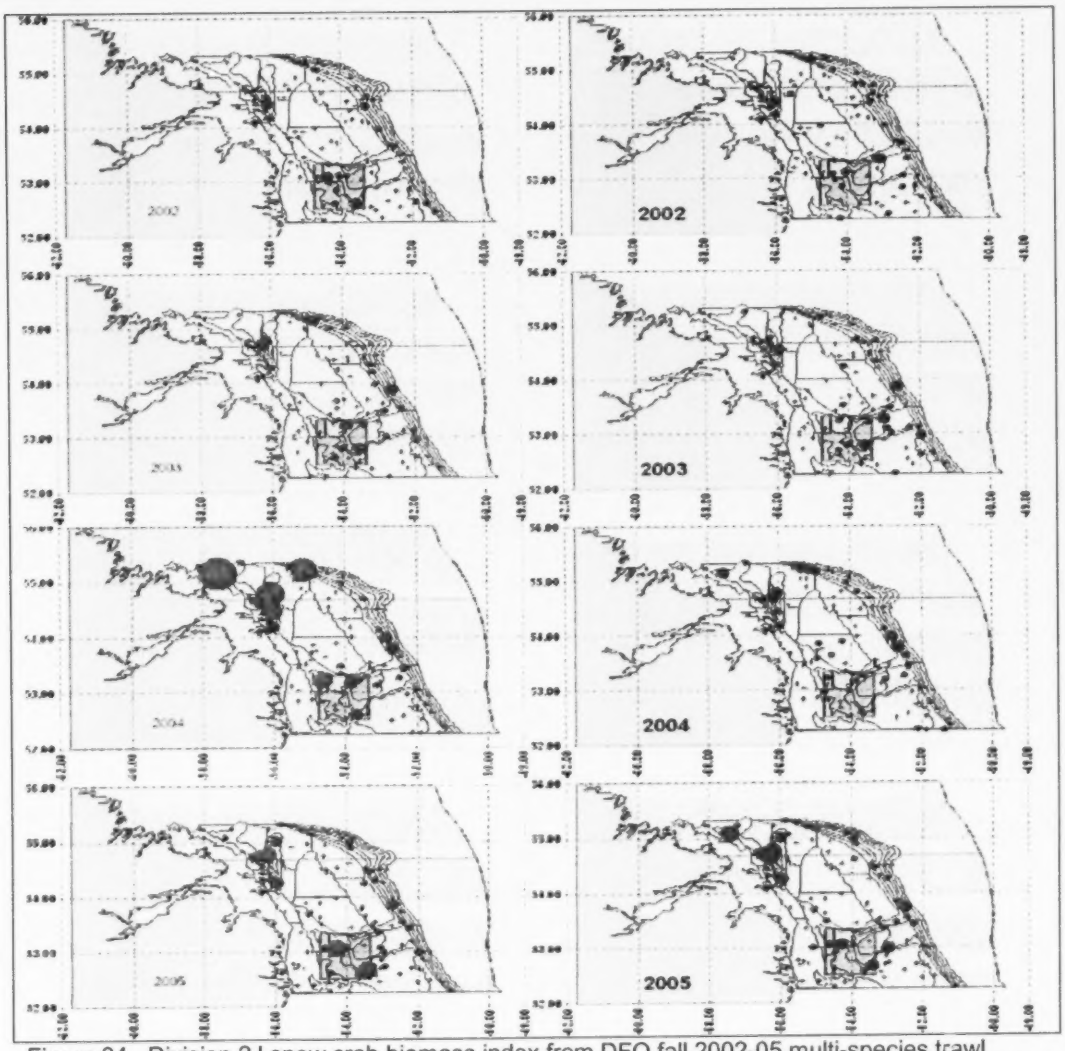

Figure 34. Division 2J snow crab biomass index from DFO fall 2002-05 multi-species trawl surveys. Pre-recruit males (76-94 mm CW) in left panels (green) vs. legal-sized males (≥95 mm CW) in right panels (teal).

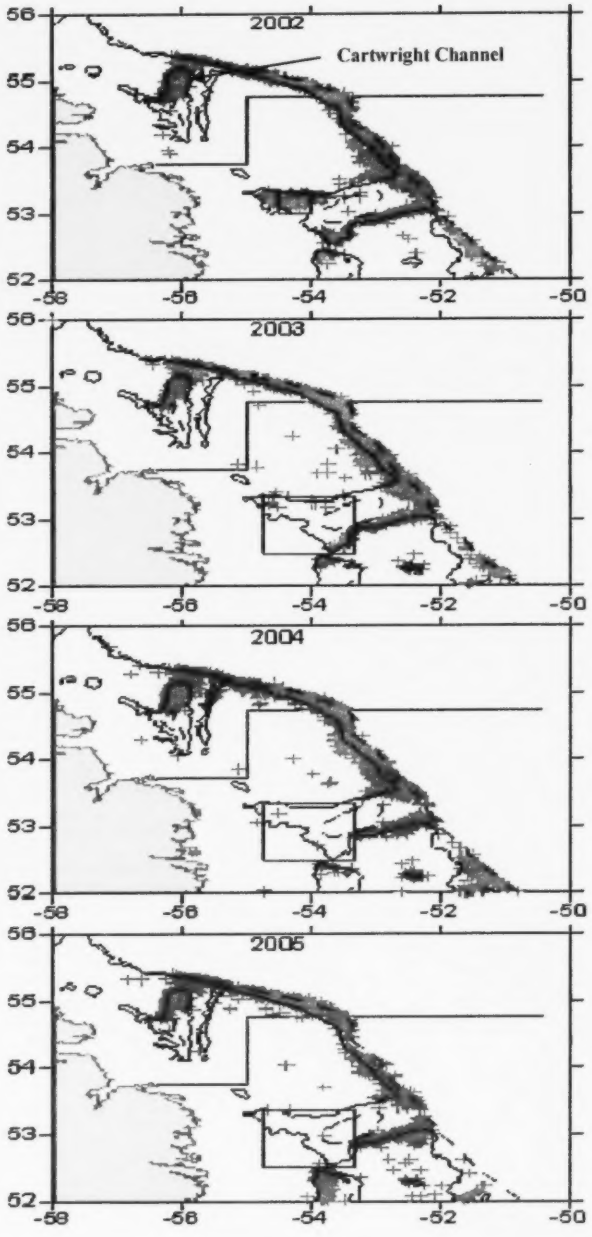

Figure 35. Location of shrimp fishing sets by the large vessel fleet in Division 2J during 2002-05 showing Hawke Channel closed area.

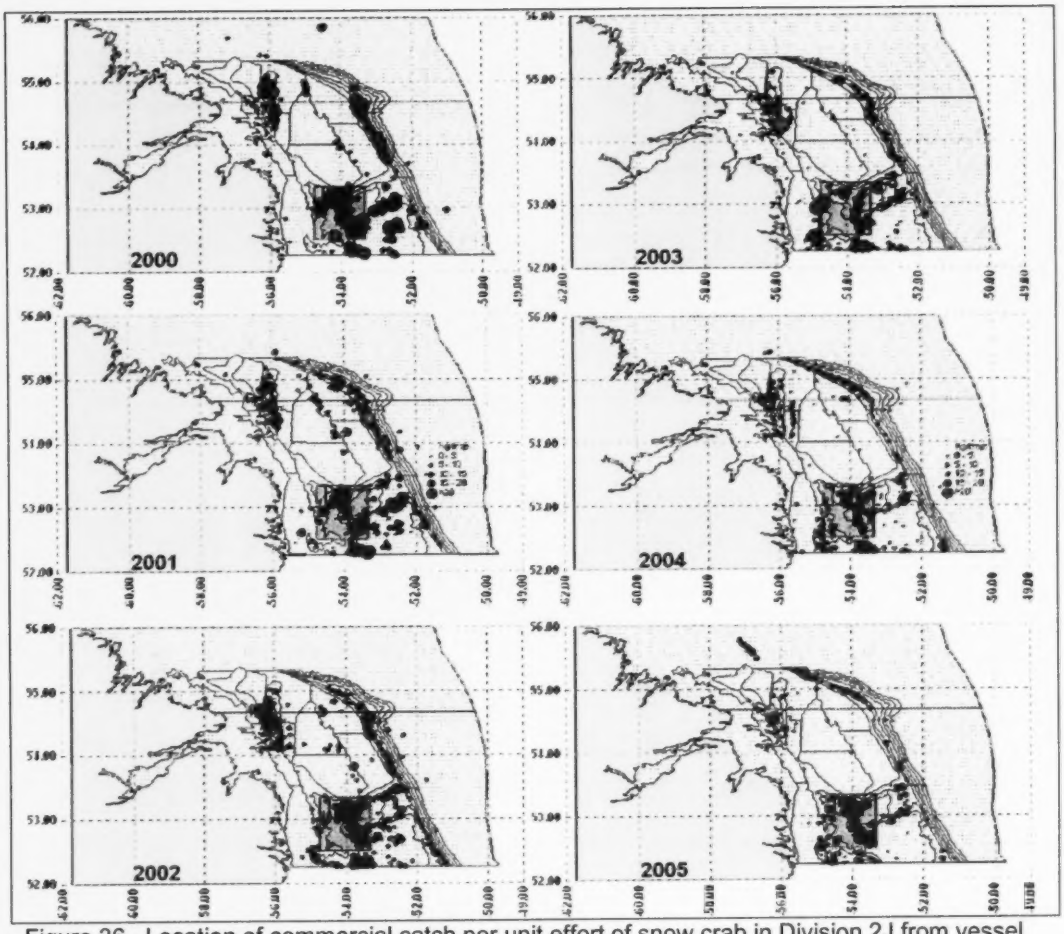

Figure 36. Location of commercial catch per unit effort of snow crab in Division 2J from vessel logbooks: 2000-05.

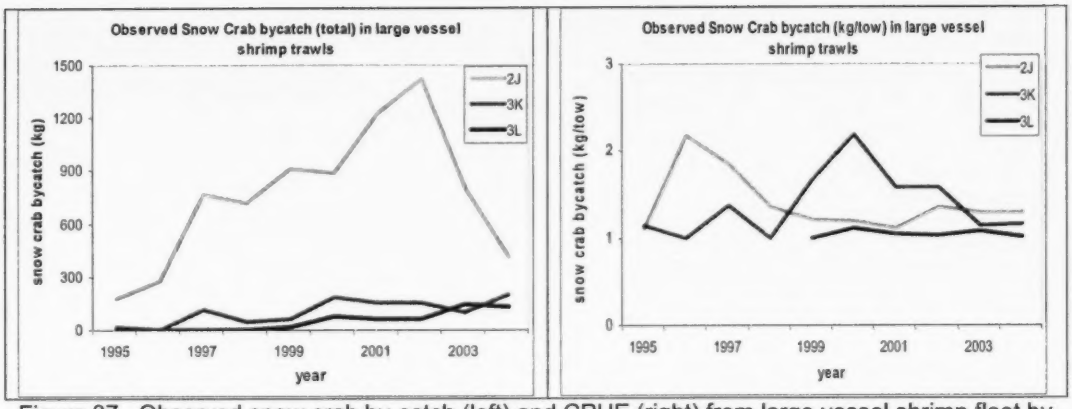

Figure 37. Observed snow crab by-catch (left) and CPUE (right) from large vessel shrimp fleet by year and NAFO Division based on 100% observer coverage, 1995-2004.

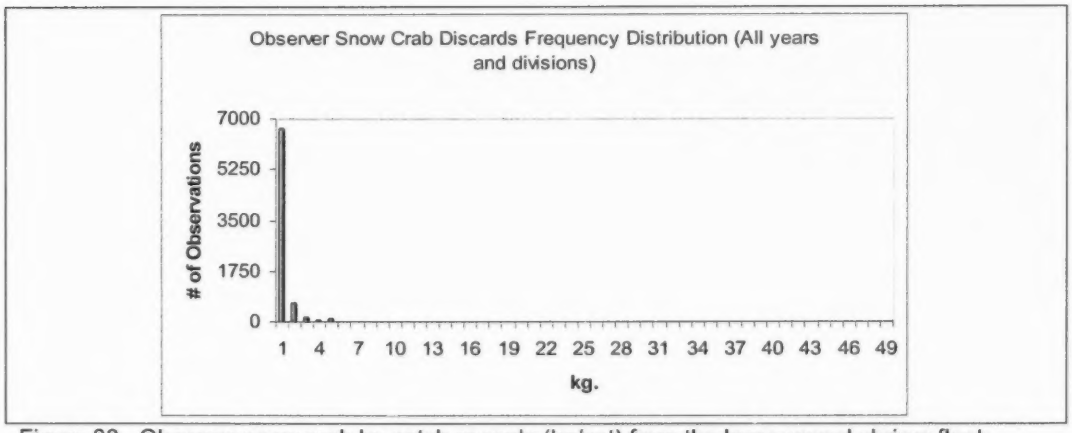
Observer Snow Crab Discards Frequency Distribution (All years and divisions)
# of Observations
7000
5250
3500
1750
0
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49
kg.

Figure 38. Observer snow crab by-catch records (kg/set) from the large vessel shrimp fleet: 1994-2005.

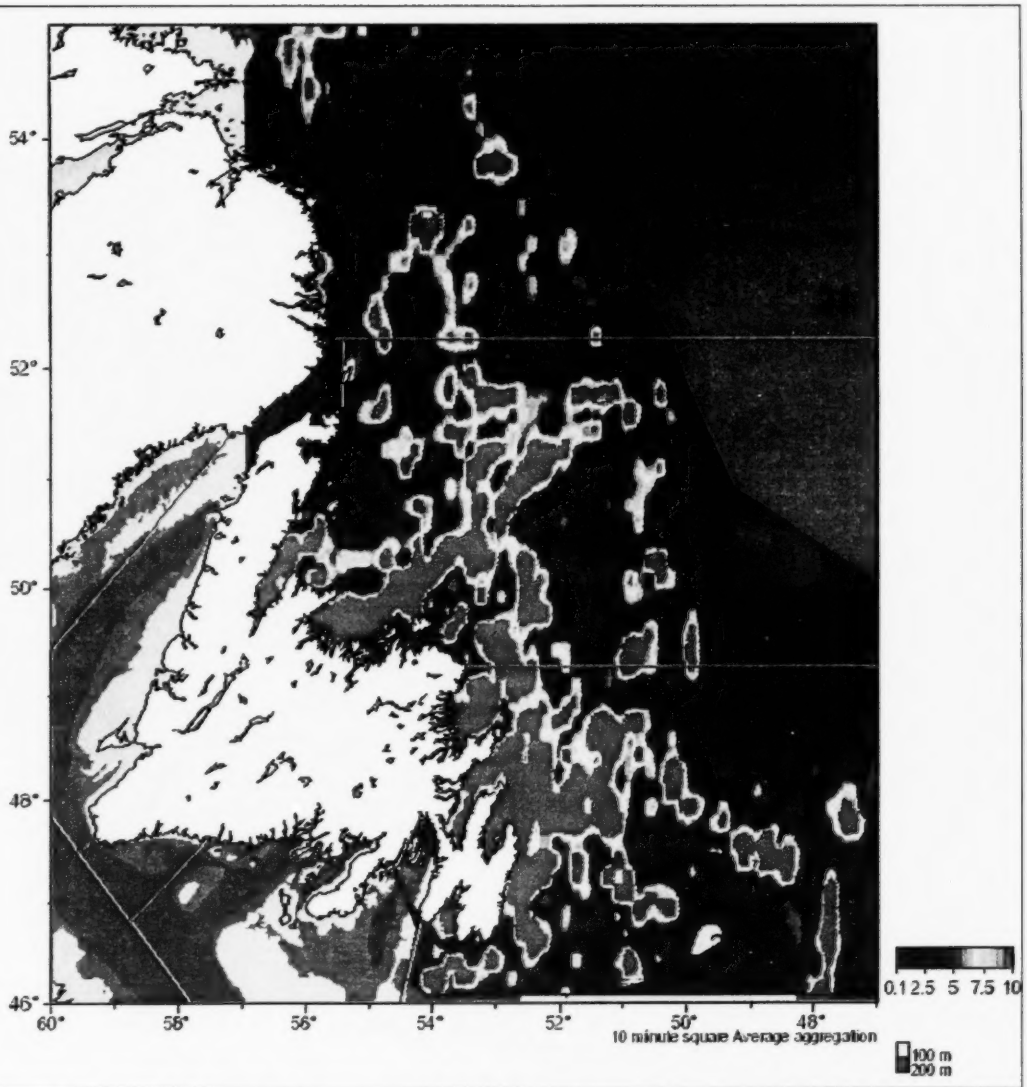

Figure 39. Spatial distribution of snow crab fishing intensity (number of trap hauls) for Division 2J3KL: 1995-2005

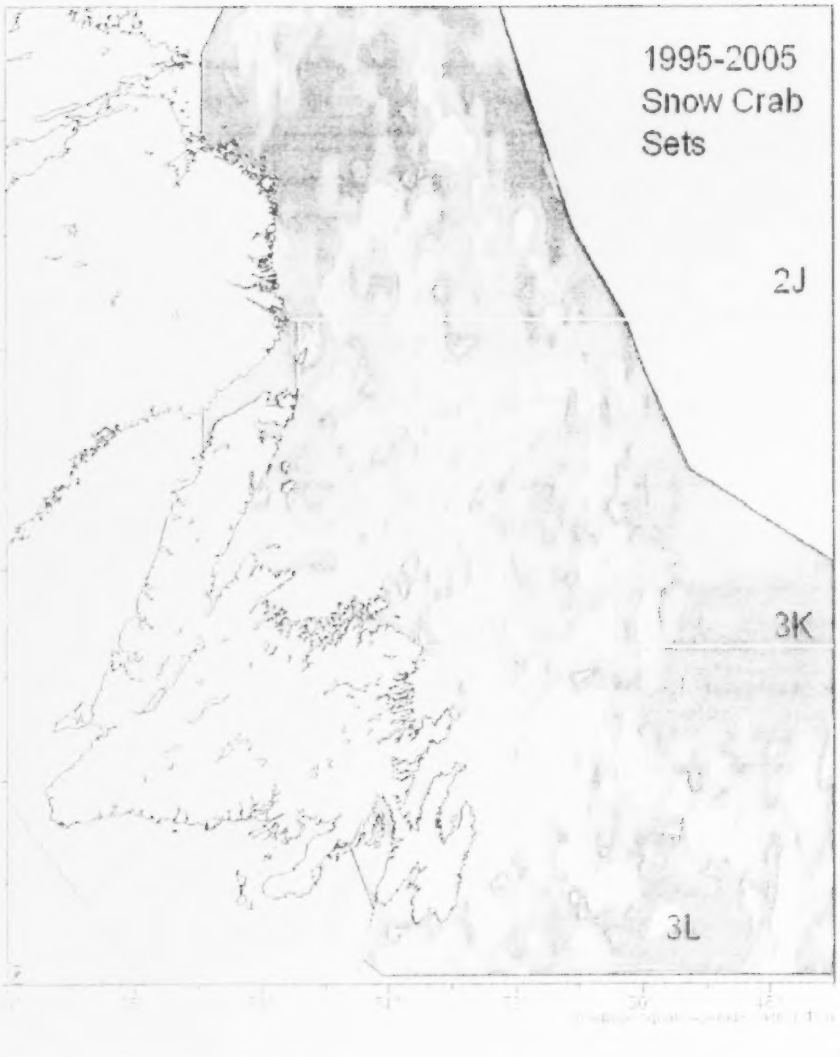

Figure 29. Spatial distribution of snow crab fishing intensity (number of trap hauls) for Division 2J3KL, 1995-2005.

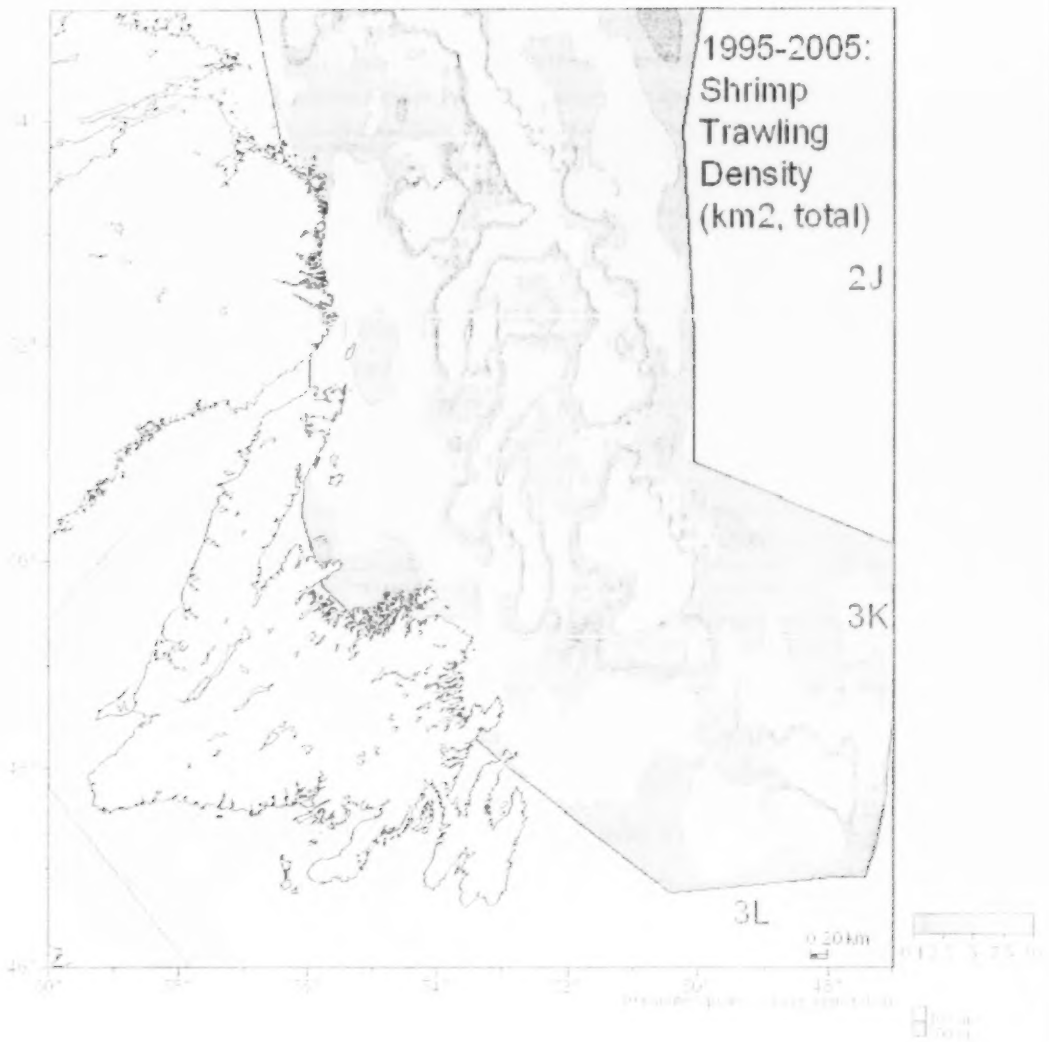

Figure 40. Spatial distribution of shrimp trawling intensity (total sq km): 1995–2005.

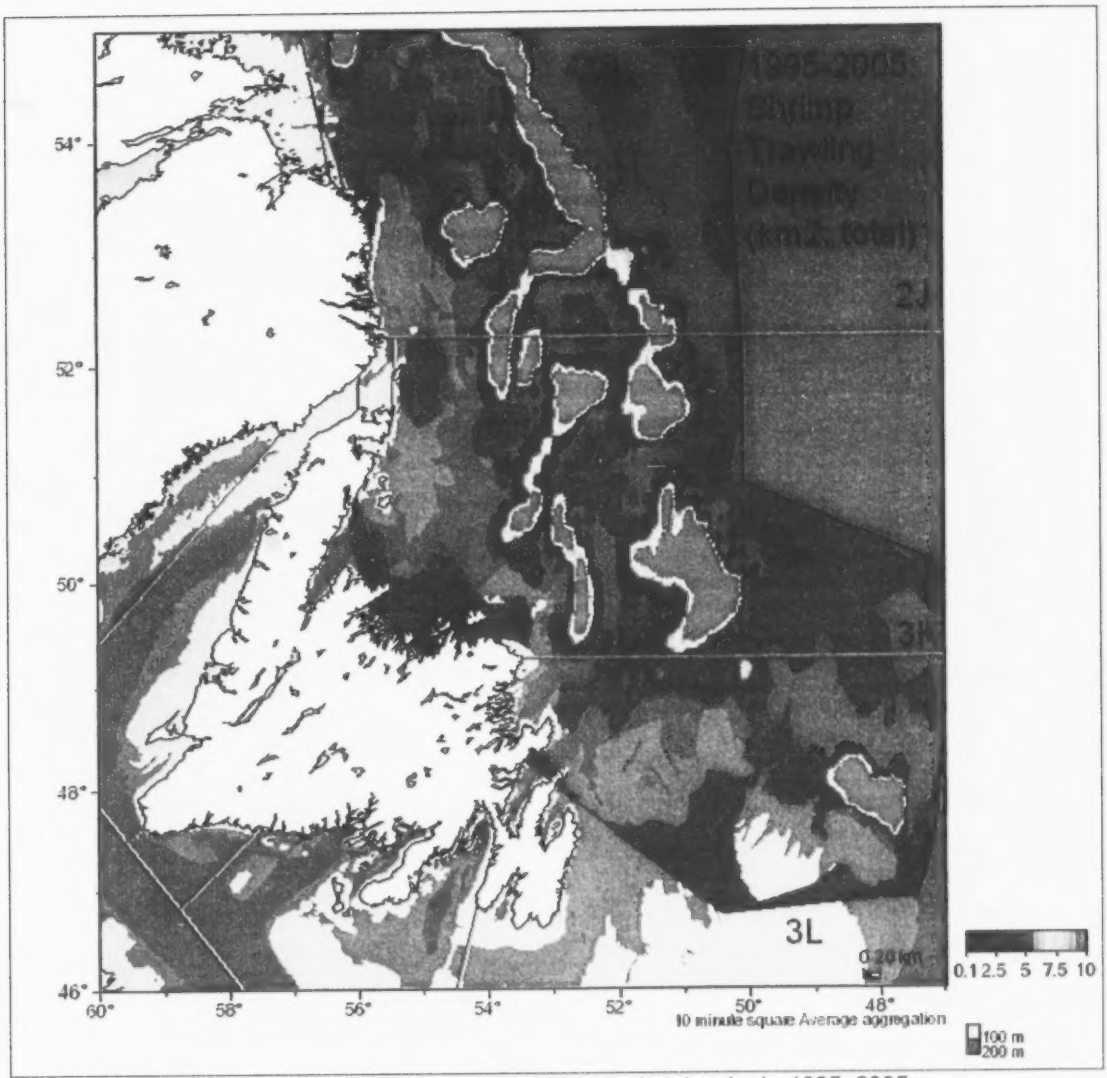

Figure 40. Spatial distribution of shrimp trawling intensity (total sq.km): 1995–2005.

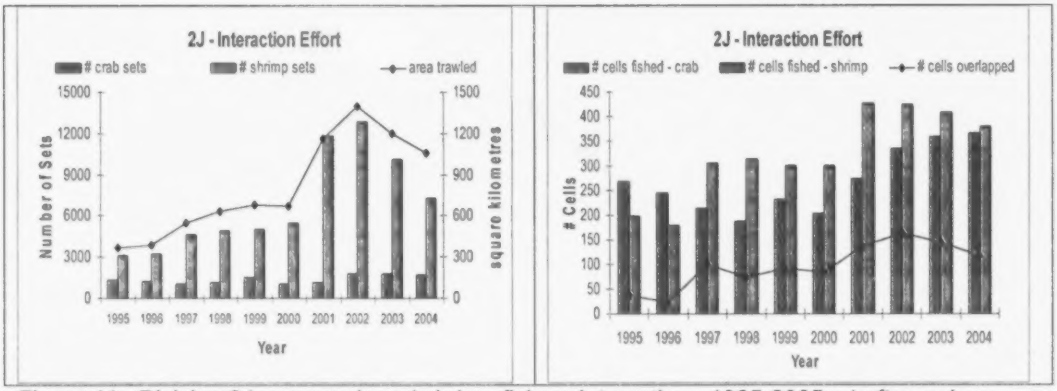

Figure 41. Division 2J snow crab and shrimp fishery interaction: 1995-2005. Left panel showing number of sets for each fishery by year and total area trawled (km2) by shrimp vessels. Right panel showing number of 5'x 5' cells fished for both fisheries by year and total number of cells overlapped.

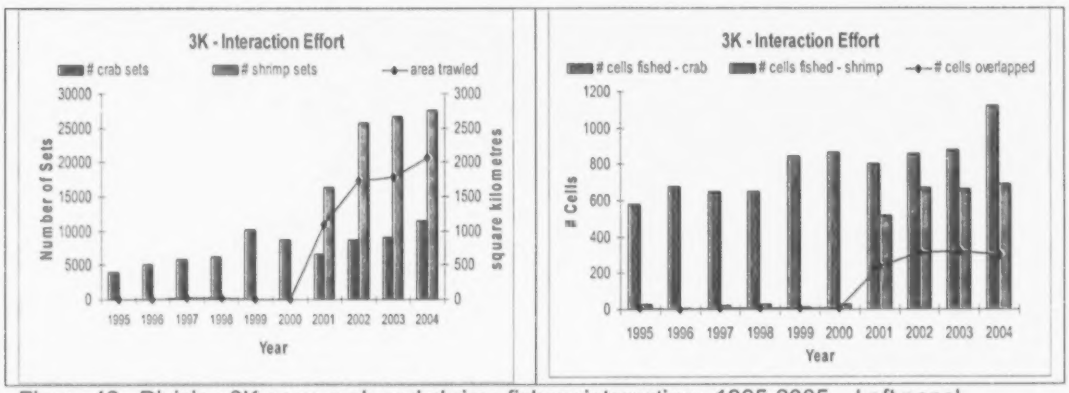

Figure 42. Division 3K snow crab and shrimp fishery interaction: 1995-2005. Left panel showing number of sets for each fishery by year and total area trawled (km2) by shrimp vessels. Right panel showing number of 5'x 5' cells fished for both fisheries by year and total number of cells overlapped.

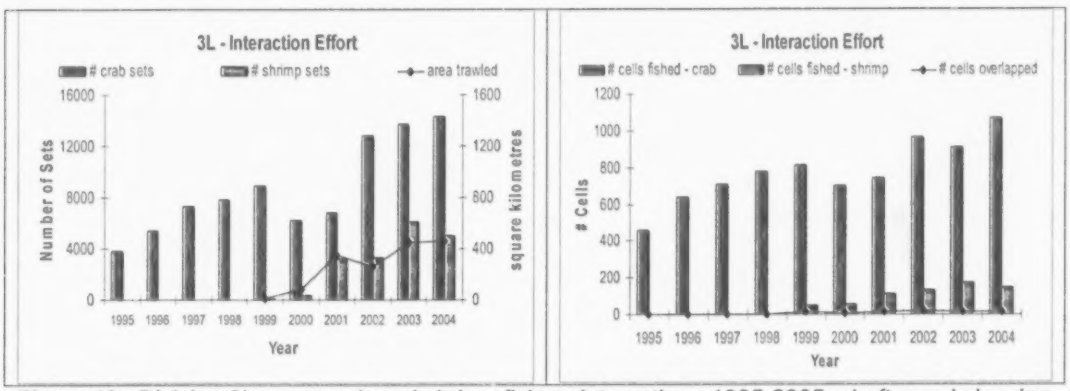

Figure 43. Division 3L snow crab and shrimp fishery interaction: 1995-2005. Left panel showing number of sets for each fishery by year vs. total area trawled (km2) by shrimp vessels. Right panel showing number of 5'x 5' cells fished for both fisheries by year vs. total number of cells overlapped.

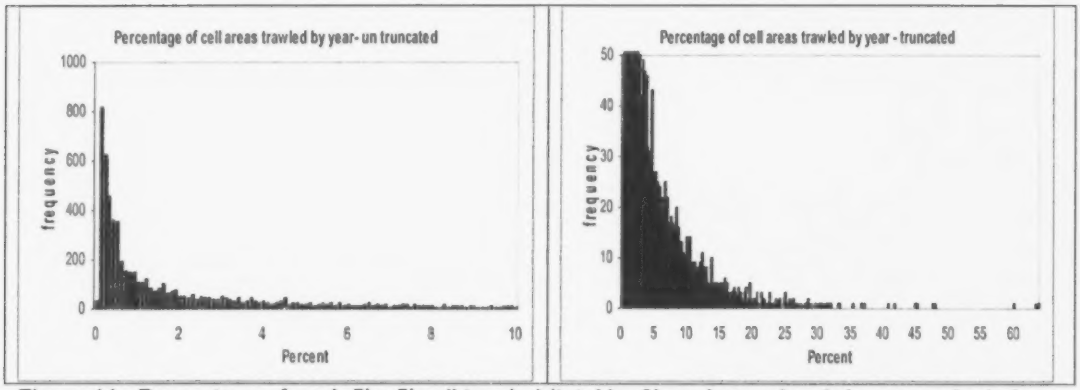

Figure 44. Percentage of each 5' x 5' cell trawled (total km2) each year by shrimp vessels during 1995-2004 for Div. 2J3KL. Each bar represents an individual cell in one year; shown as non-truncated (left panel) and truncated (right panel) distributions.

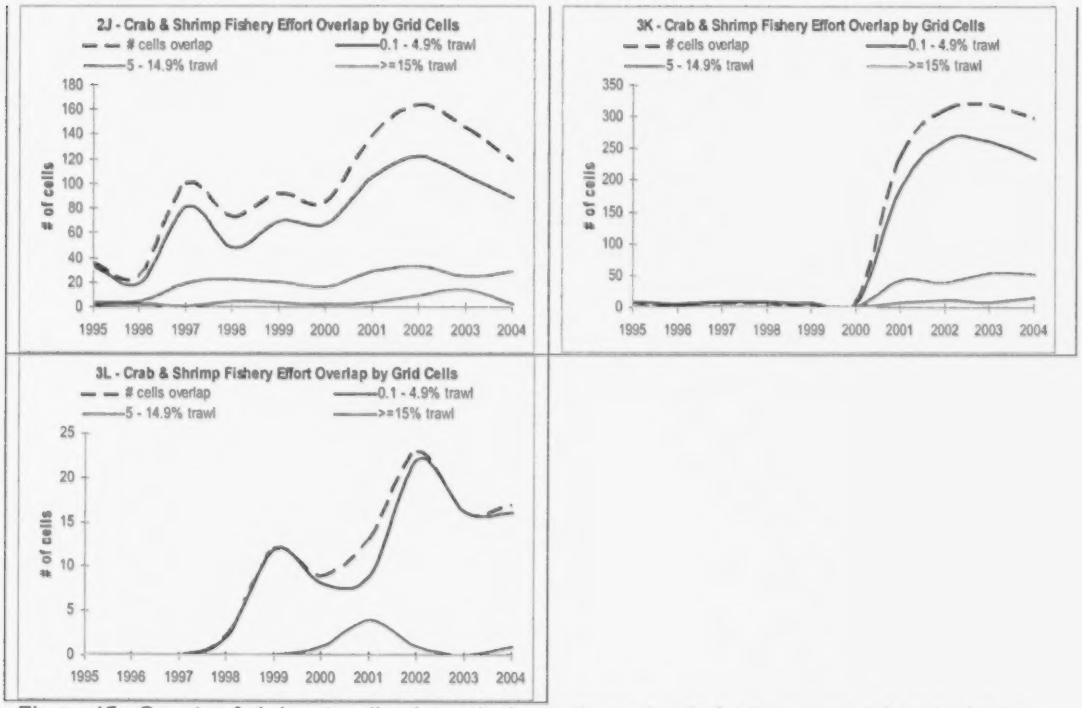
2J - Crab & Shrimp Fishery Effort Overlap by Grid Cells
cells overlap
0.1 - 4.9% trawl
5 - 14.9% trawl
>=15% trawl
# of cells
3K - Crab & Shrimp Fishery Effort Overlap by Grid Cells
cells overlap
0.1 - 4.9% trawl
5 - 14.9% trawl
>=15% trawl
# of cells
3L - Crab & Shrimp Fishery Effort Overlap by Grid Cells
cells overlap
0.1 - 4.9% trawl
5 - 14.9% trawl
>=15% trawl
# of cells

Figure 45. Counts of shrimp trawling intensity in overlapped cells for the snow crab and shrimp fisheries: 1995-2005. Division 2J (top left panel), Division 3K (top right panel) and Division 3L (bottom left panel).